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TIME LIMITS FOR COMPLETING FIXED RATIOS. III. STIMULUS VARIABLES[1]

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Pigeons received food only if they took longer than a specified time to begin and complete a fixed ratio. In Experiment 1, ratios with shorter durations had no stimulus consequence; in Experiment 2, these ratios ended with a stimulus change. In both studies, the mean time to complete the ratio exceeded requirements of less than 30 sec, approximately matched requirements of 30 sec, and fell progressively short of matching thereafter. Variability increased together with the means. The various effects resembled those of temporal differentiation experiments involving single responses. Although both number of ratios and time separating successive food presentations increased along with ratio duration, control experiments showed that differential reinforcement of duration, rather than either form or reinforcer intermittency, accounted for the performance. Experiment 2 also studied the effects of adding a stimulus that signalled when the required time had elapsed. The stimulus produced durations that matched even the most stringent requirements. This precision was not maintained when the stimulus was removed. Temporal differentiation schedules seem to have similar effects regardless of the response class and temporal property involved.

In a temporal differentiation schedule, the presentation of a reinforcing stimulus depends on the duration of behavior. The duration can be of an individual event such as the latency, duration, or interresponse time of a bar press (*e.g.,* Skinner, 1938), or it can refer to an entire sequence, such as the initial pause in a fixed-ratio schedule (Findley, 1962; Kelleher, Fry, and Cook, 1964) or the time taken to traverse an alley (Logan, 1960). Parametric studies involving both individual responses and sequences have demonstrated that performance adjusts to temporal requirements under a range of criterion values (Catania, 1970—response latency; Malott and Cumming, 1964; Staddon, 1965—interresponse time; Platt, Kuch, and Bitgood, 1973—bar-press duration; Zeiler, 1970, 1972—the duration of the fixed-ratio sequence). The data suggest that the effects of a temporal differentiation schedule may be independent of the particular behavior specified. The present experiments explored this implication by extending the analysis of fixed-ratio sequences.

EXPERIMENT 1: RATIO TIME DIFFERENTIATION WITH A CONTINUOUS PROCEDURE

Temporal differentiation studies involving individual responses have used two different procedures. In both, responses that conformed to the requirement produced a reinforcer. However, in one ("continuous procedure") inappropriate responses had no scheduled consequences, whereas in the other ("signalled procedure"), these responses produced a stimulus change. The continuous procedure has been used in studies of interresponse time (Malott and Cumming, 1964; Staddon, 1965) and response duration differentiation (Platt *et al.,* 1973); the signalled procedure has been used with response latency (Catania, 1970; Logan, 1961) and response duration (Platt *et al.,* 1973). In contrast, experiments dealing with sequences all used the signalled procedure. Therefore, the generality of the similarity hitherto observed between individual responses and sequences remains unclear.

The present experiment involved the continuous procedure in the differentiation of ratio time, *i.e.,* the time from the first opportunity to respond to the completion of a fixed

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ratio (FR). When the time exceeded the specified duration, food was presented. Shorter times began the ratio anew, with no stimulus change indicating the completion of one ratio and the beginning of the next.

With required times longer than 30 sec, many ratios had durations too short to produce food, and raised the question of the contribution of intermittency of reinforcer presentation to the performance. This, of course, is a possibility in any differentiation experiment, whether it involved individual responses or sequences and used the continuous or the signalled procedure. For example, when Staddon (1965) varied interresponse-time requirements, as the required times increased so did the intermittency of food presentation. The present experiment investigated whether intermittency with respect to either time or the number of ratios emitted between food presentations could be responsible for the performance observed with the temporal differentiation schedule.

METHOD

Subjects

Four adult White Carneaux pigeons were maintained at 80% of their free-feeding weights. Birds P-101, P-110, and P-128 had experience with a variety of compound and simple schedules of reinforcement; P-132 was experimentally naive.

Apparatus

The experimental chamber was a single-key pigeon unit (Ferster and Skinner, 1957). Two 3-W lights, one in each upper corner of the response panel, provided dim general illumination. The 2-cm diameter response key, operated by a minimum force of 0.18N, could be transilluminated by two 3-W red lamps. A relay mounted behind the panel next to the key provided auditory feedback for each response. A 5-cm square aperture centered 8 cm below the key provided occasional access to Purina Pigeon Checkers, the birds' standard diet. During the 4-sec feeder cycles, the aperture was illuminated by a 1-W white light, and the key and houselights were turned off. All lamps were operated from a power supply different from that controlling the scheduling equipment, so that there would be no flicker correlated with scheduled events. White noise masked extraneous sounds.

Procedure

Ratio time differentiation. The schedule was an FR 30: the ratio began anew after every thirtieth response. The duration of the ratio (ratio time) consisted of either the time between the last response of one ratio and the last response of the preceding ratio, the time between the end of a feeder cycle and the last response of the following ratio, or the time from the beginning of the session until the last response of the first ratio. If ratio time exceeded that specified, food was presented at the completion of the ratio; if it was less than that specified, the completion of the ratio began the response and time requirement anew. There was no stimulus change after a ratio having a duration shorter than that required.

At first there was no time requirement (a simple FR 30, or, alternatively, an FR 30 with a 0-sec time requirement). The time criteria used were 0, 16, 30, 50, 75, and 100 sec, imposed first in an ascending and then in a descending order.

Each requirement was maintained for 30 sessions. Sessions lasted for 30 food presentations or for 2 hr, whichever occurred first. There were five sessions per week.

Second-order schedules: reinforcer density controls. After the descending series of time requirements, the criterion was set at 50 sec for 30 sessions. (1) The time between successive food presentations (interfood interval) occurring during each of the last 10 sessions of this condition was used to establish 10 separate sequences of interfood intervals. Each session of the next condition was yoked to one of the sequences. The first FR 30 completed when each interfood interval had elapsed was followed by food, and all others began the FR 30 anew. As a result, the sequence of minimum interfood intervals occurring with the 50-sec time requirement was maintained, but the time requirement was eliminated. In Kelleher's (1966) notation system, this was a VI *t* (FR 30) second-order schedule, with *t* describing the average interfood interval. The 10 different sequences occurred in the order 1 to 10 three times (30 sessions). Each session lasted as long as had the 50-sec differentiation session on which it was based.

(2) Varying numbers of FR 30 sequences occurred between the successive food presentations of the last ten 50-sec differentiation

sessions. The sequence of numbers was used to arrange 10 schedules yoked in terms of number of responses per food presentation. When the appropriate number of ratios had been emitted, the next was followed by food presentation. This meant that there was no time specification, but the sequence of number of ratios per food presentation in each session of this condition was the same as it had been in one of the final 10 sessions of the differentiation condition. This was a VR *n* (FR 30) second-order schedule (with *n* describing the average number of ratios per food presentation) yoked to the differentiation condition in terms of the number and sequences of ratios ending with and without food. The 10 VR *n* (FR 30) schedules occurred in the order 1 to 10 three times (30 sessions). Each session lasted until the number of completed ratios equalled the number occurring during the differentiation schedule on which it was based.

Finally, there were 30 sessions with the 50-sec time requirement. Comparison of performances under the 50-sec requirement before and after the two reinforcer density control conditions revealed how the interpolated intermittent reinforcement of simple FR 30 performance influenced behavior under a differentiation schedule.

RESULTS AND DISCUSSION

Ratio Time Differentiation

Figure 1 shows the relation between mean ratio time over the last 10 sessions of each condition involving time requirements. The heavy diagonal line shows the curve that would result if the emitted times always matched the required times. The emitted times exceeded those required at 16 sec, and approximately matched at 30 sec. Ratio times increased as the requirement increased beyond 30 sec, but matching no longer occurred. Instead, with each progressively longer requirement, the ratio times increasingly departed from matching. The dashed line of Figure 1 describes a power function fit by the least-squares method to the mean ratio times. Although the range of requirements used did not permit differentiating between fits provided by power or linear functions, the power function was used to compare these with other data.

In the cumulative records of Figure 2, the response pen stepped once after each 30 responses. The records are from the ascending series of requirements, but they were representative of all exposures to a given condition. At all values, successive ratios were emitted at a fairly steady rate, but the slopes (rate) decreased with each successively longer requirement. Food presentations tended to be clustered, with the number within each cluster decreasing and the time between clusters increasing as the requirement increased. The clustering of food presentations also occurs with interresponse-time differentiation (Kelleher, Fry, and Cook, 1959; Staddon 1965). Conventional cumulative records in which each response stepped the pen indicated a generally steady rate of responding within each ratio. Pauses occurred within ratios, but they had no consistent relation to either the number of responses emitted or time. Food presentations often were followed by pauses: this perhaps was at least in part responsible for

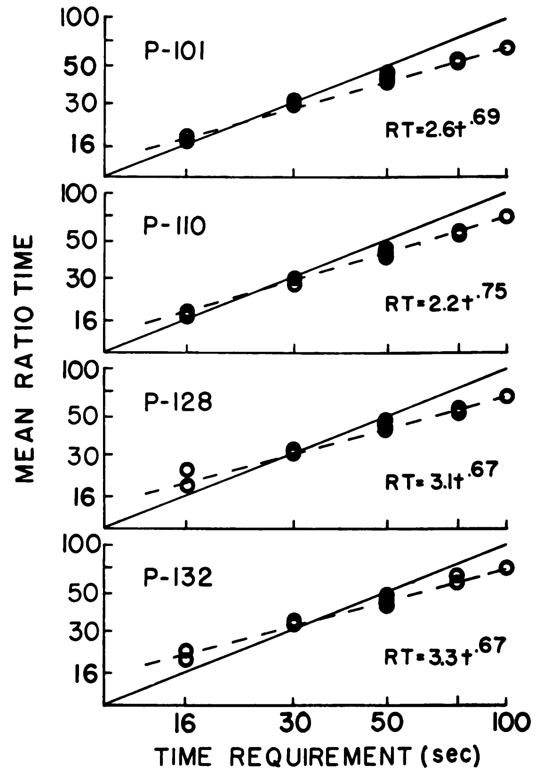

Fig. 1. Ratio time under each requirement plotted on logarithmic scales. Each point is the mean for the last 10 sessions of a condition. The solid diagonal line represents matching between emitted and required times. The equation and the dashed line is for the best-fitting power function. RT is the mean ratio time, and *t* is the time requirement in seconds.

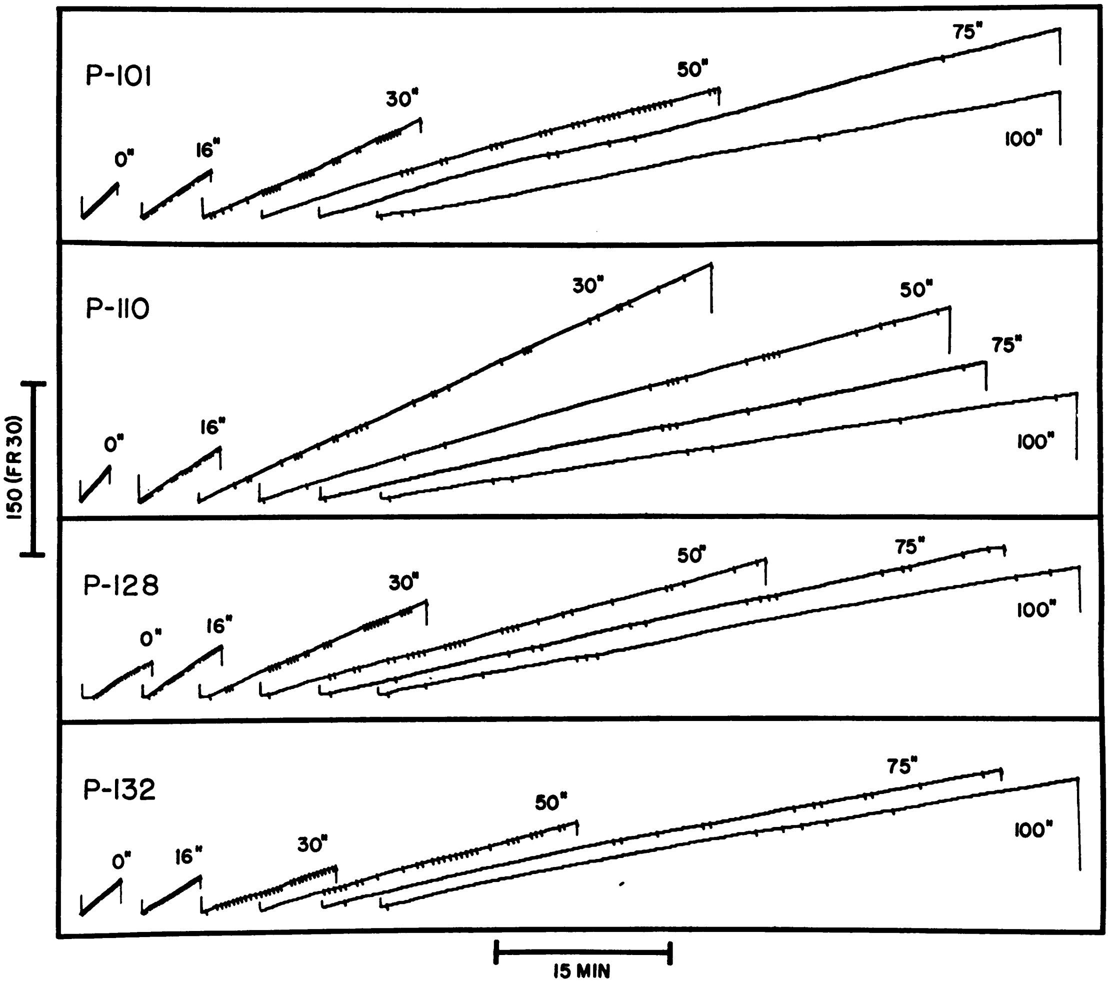

Fig. 2. Cumulative records for the last session of each condition. The response pen stepped once for each 30 responses. Offsets of the response pen indicate food presentations.

the clustering of food presentations, in that pausing tended to increase ratio time. Without food presentations, response rate from the end of one ratio to the beginning of the next changed little.

Individual ratio times during the last 10 sessions of each condition were collected in bins. With the 0-sec and 16-sec requirements, bins 2 to 10 were 2 sec wide; with all others, they were 10% of the requirement. Bin 1 contained all times shorter than the lower bound of bin 2, and bin 11 contained all times longer than the upper bound of bin 10. The lower bound of bin 2 was adjusted to have the maximum number of ratio durations appear in bins 2 to 10. Figure 3 shows frequency distributions under the ascending and descending requirements combined: replications were pooled, since the separate distributions did not differ. The mean and standard deviation of ratio times appears adjacent to each distribution. Mean and modal times increased with longer requirements, but the proportion of ratios having sufficiently long durations to end with food presentation decreased. Changes in the standard deviation indicated that variability increased along with the means.

Intermittency Versus Differentiation

During the last 10 sessions of the third exposure to the 50-sec ratio time requirement, the time between successive food presentations ranged from 50 sec to 3450 sec for P-101, from 50 sec to 1086 sec for P-110, from 50 sec to 1428 sec for P-128, and from 50 sec to 2190 sec for P-132. The number of ratios between presen-

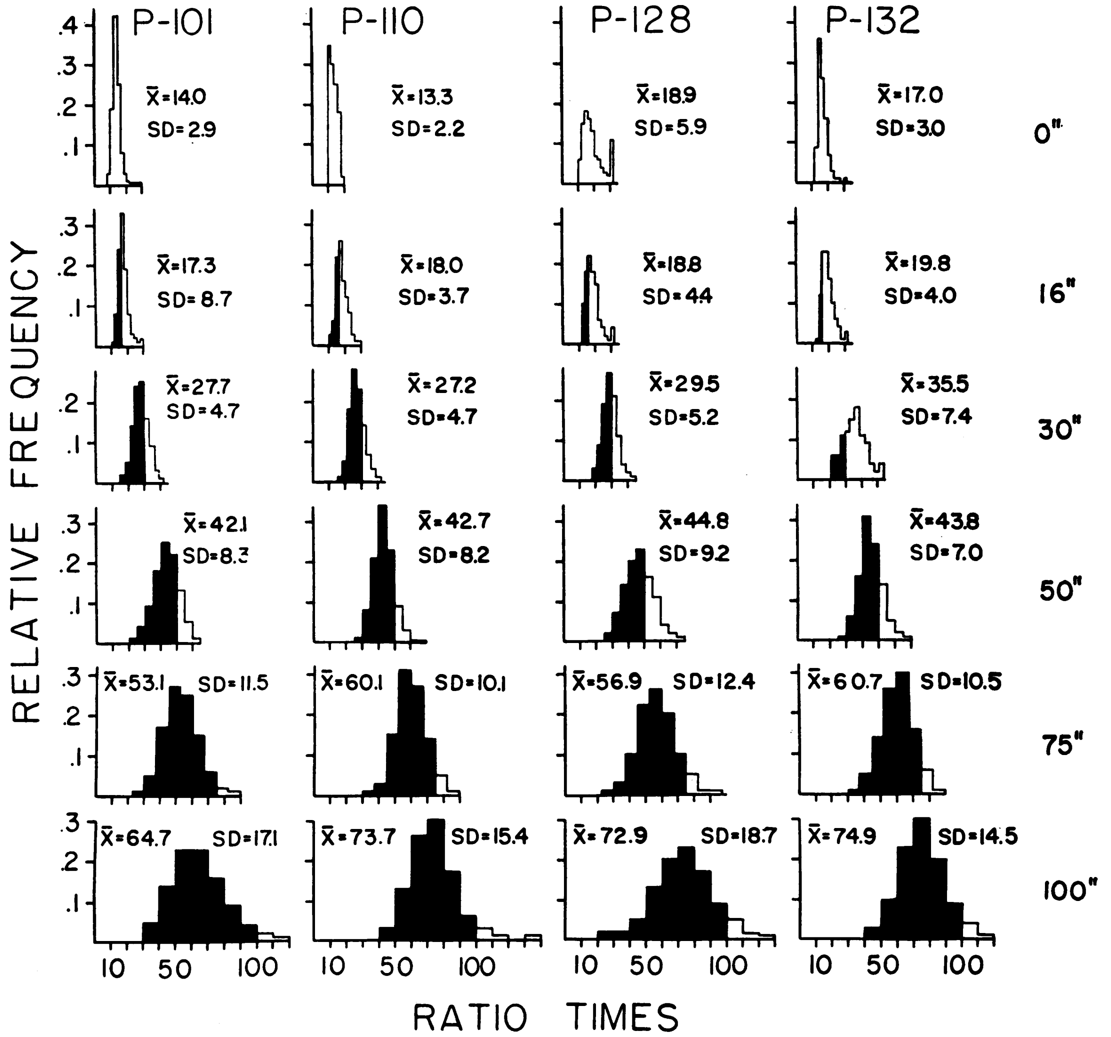

Fig. 3. Relative frequencies of ratio times pooled over the last 10 sessions of the ascending and descending series. The requirements are shown next to their corresponding distributions. The unshaded areas of each distribution represent ratios followed by food presentation. Standard deviations were computed from the frequency distributions by use of midpoints. Non-zero values for bins 1 and 11 were approximated by assuming these bins to be the same width as the others.

tations ranged from 1 to 78 for P-101, from 1 to 24 for P-110, from 1 to 30 for P-128, and from 1 to 52 for P-132. The mean interreinforcer interval was 332 sec for P-101, 172 sec for P-110, 167 sec for P-128, and 319 sec foı P-132. The average number of ratios per food presentation was 8.0 for P-101, 3.9 for P-110, 3.8 for P-128, and 7.3 for P-132.

The distribution of ratio times occurring with the 50-sec requirement condition was like that on the previous exposures to that condition (Figure 4, upper row). The second-order schedules derived from it did not maintain the same distribution, but it was recovered under the final exposure to a 50-sec requirement (Figure 4, bottom row). Under the VI (FR 30) schedules (second row) and the VR (FR 30) schedules (third row), the frequency of shorter ratio times increased. Cumulative records indicated that responses occurred at a generally steady rate, separated by periods of pausing. The differences in performance under the differentiation schedule and the two second-order schedules showed that time requirements *per se* were important independent of the density of food presentation obtained.

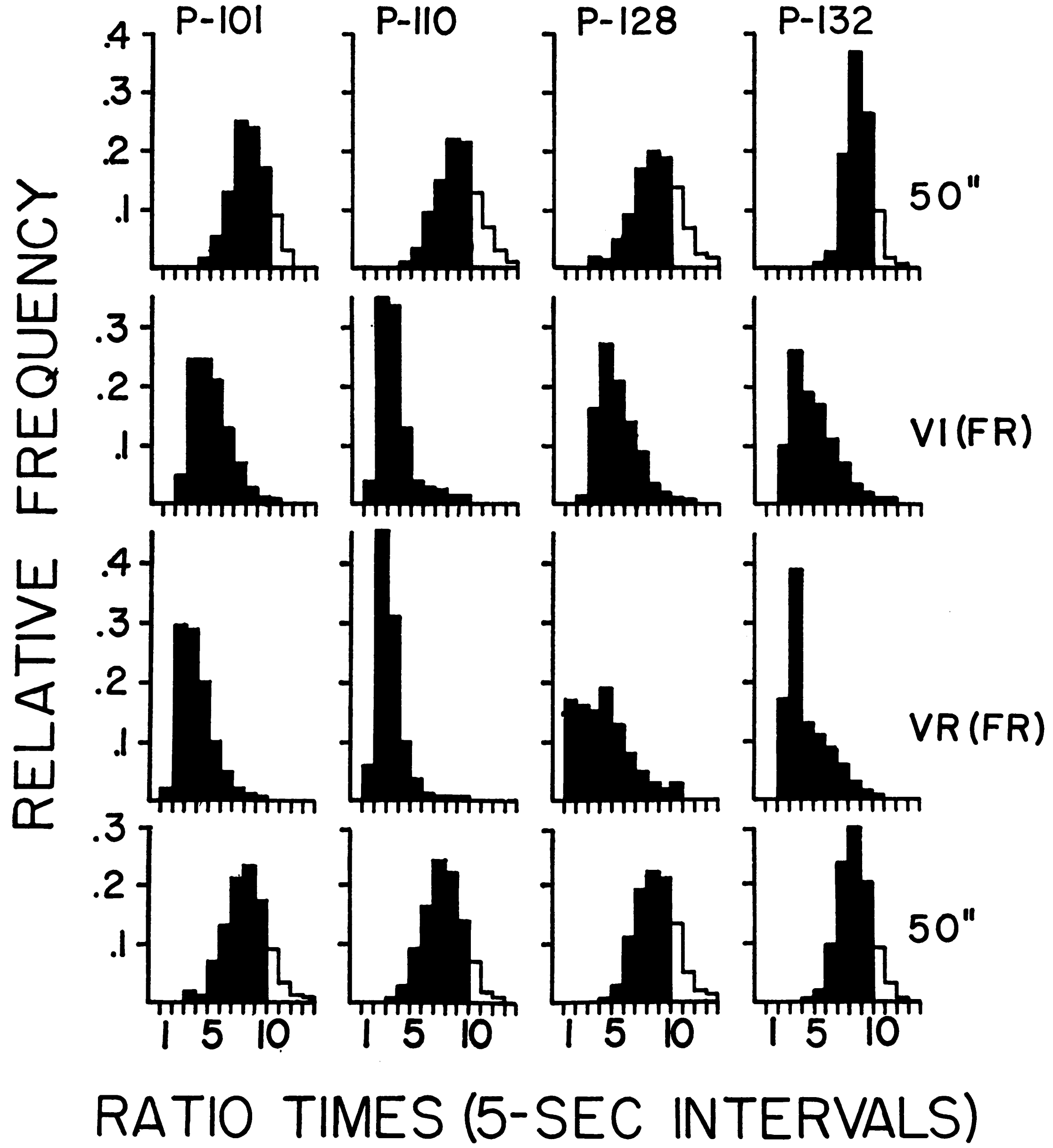

Fig. 4. Relative frequencies of ratio times occurring during the last 10 sessions of the third exposure to the 50-sec requirement, the yoked VI (FR 30) second-order schedule, the yoked VR (FR 30) second-order schedule, and the final 50-sec requirement. The unshaded areas with the 50-sec requirement indicate ratio times followed by food presentation.

EXPERIMENT 2: STIMULUS CONTROL IN RATIO TIME DIFFERENTIATION

Experiment 1 showed that with a continuous procedure in which no exteroceptive stimulus consequences followed ratio durations too short to meet the requirement, an orderly relation existed between emitted and required durations. The data conformed to those involving other temporal aspects of behavior (Catania, 1970; Platt, *et al.,* 1973), in that the emitted durations exceeded or matched short requirements, but then increasingly departed from matching at progressively longer requirements. No existing evidence indicates whether this general function characterizes ratio time differentiation when every ratio is followed by a distinctive stimulus event (signalled procedure), perhaps because the largest requirements used were in the range that produced matching (Zeiler, 1970, 1972). The present experiment, therefore, extended the range of parameter values involved in differentially reinforcing the duration of fixed-ratio sequences with the signalled procedure.

Another purpose of this experiment was to investigate the effects of adding a stimulus that indicated when the required duration had elapsed. When McMillan (1969) presented food to pigeons only if interresponse times exceeded 20 sec, the interresponse-time distributions were shallow with modal values of less than 20 sec. However, if a stimulus changed whenever 20 sec elapsed without a response, the distributions peaked sharply at a value slightly more than 20 sec. Other investigators also have used an added stimulus to obtain precise control of interresponse times (Reynolds, 1966; Reynolds and Limpo, 1968), and of response durations (Stevenson and Clayton, 1970). If temporal differentiation effects are independent of the response unit and particular duration involved, signalling that the required time has elapsed should exert similar effects when used in the context of differential reinforcement of long ratio times.

METHOD

Subjects

Four adult White Carneaux pigeons were maintained at 80% of their free-feeding weights. Birds P-16 and P-56 had served in earlier experiments involving differential reinforcement of the duration of fixed ratios; P-124 had experience with multiple fixed-ratio extinction schedules, and P-135 was experimentally naive.

Apparatus

The experimental chamber was a single-key pigeon unit (Grason-Stadler E1100 PB) modified by substituting a Lehigh Valley Electronics 1347 grain feeder and adding a relay mounted on the back of the panel next to the key that provided auditory feedback for each response. The 2-cm diameter response key, operated by a minimum force of 0.18N, could be transilluminated by either red, blue, or white 7-W lamps. There was no houselight. Stimulus events during the feeder operations were as described for Experiment 1. White noise masked extraneous sounds.

Procedure

Ratio time differentiation. The schedule was an FR 30: every thirtieth response resulted in either a 4-sec food presentation or a 4-sec key-color change from red to blue (a timeout). Responses during a timeout had no scheduled consequences. After either food or a timeout, the key again became red and the ratio began anew.

Table 1

Sequence of Conditions

Condition	*Time Requirement (seconds)*	*Sessions*
1	0	30
2	30	16
3	100	31
4	100 + stimulus	34
5	100	24
6	300	25
7	300 + stimulus	14
8	300	30
9	100	13
10	30	13
11	0	14
12	[a]	14
13	65	23
14	200	14
15	200 + stimulus	21
16	100	19
17	0	34
18	VI *t*(FR 30) 0	29
19	VR *n*(FR 30) 100	30

[a] The time requirement was the mean ratio time of Condition 11. P-16: 10 sec; P-56: 18.5 sec; P-124: 15 sec; P-135: 13.5 sec.

The duration of the ratio (ratio time) was the time between the onset of the red keylight and the last response of the ratio. If ratio time exceeded that specified, food was presented; if it was less than that specified, the timeout occurred. The sequence of requirements is shown in Table 1 as Conditions 1-3, 5-6, 8-14, and 16. At first there was no time requirement, and then requirements of 30, 65, 100, 200, 300-sec, and the average ratio time emitted under the simple FR 30 schedule (10, 18.5, 15, and 13.5 sec for P-16, P-56, P-124, and P-135 respectively) were imposed.

Conditions were changed for all birds only when the performance of all had stabilized. Mean ratio time (the sum of the individual ratio times divided by the total number of ratios completed) was computed for each session. The median value of three successive session means was then calculated. Performance was considered stable when three consecutive medians (based on nine consecutive sessions) showed no consistent increasing or decreasing trend.

Sessions lasted for 20 food presentations or for at least 2.5 hr. There were five sessions per week.

Differentiation with added stimulus. The effects of a stimulus correlated with elapsed time were studied with 100-sec (Condition 4), 300-sec (Condition 7), and 200-sec (Condition 15) requirements. Whenever the time criterion elapsed before the ratio was completed, the key color changed from red to white. Thus, food followed ratios completed only while the key was white; ratios completed when the key was red ended with a timeout. Each stimulus condition except the last was preceded and followed by the same requirement without an added stimulus. Condition 15 (200-sec requirement) was followed by a 100-sec condition in order to ascertain if an immediate history of long ratio times would carry over to a less-stringent condition not accompanied by the stimulus.

Second-order schedules: reinforcer density controls. The last four sessions of the 100-sec differentiation requirement of Condition 16 were used to establish second-order schedules yoked in terms of interreinforcer time or number of ratios per reinforcer. With the exception of being based on four sessions rather than 10, the procedure was identical to that of Experiment 1. Condition 17 was the VI (FR 30) control, and Condition 18 the VR (FR 30) control. The four different daily sequences were used in a random order, with the limitation that each appear once in each block of four sessions. Thus, the sequence of food presentations in relation to time (Condition 17) and ratios (Condition 18) remained identical to that occurring with the 100-sec requirement of Condition 16. For P-16 and P-124, this meant that one of every four sessions had no food presentations. The final condition (Condition 19) was an FR 30 schedule with a 100-sec time requirement. Comparison with Condition 16 revealed how the interpolated intermittent reinforcement of simple FR 30 performance influenced behavior under a differentiation schedule.

Results and Discussion

All data analyses were based on the individual ratio times (in seconds) of the last four or five sessions of each condition. Five sessions were used sometimes so that at least 100 ratios were always involved.

Ratio Time Differentiation

Figure 5 shows the relation between mean ratio time and the time requirements. Only Condition 19 is excluded, because it had distinctive effects to be discussed later. All other exposures to a given duration requirement

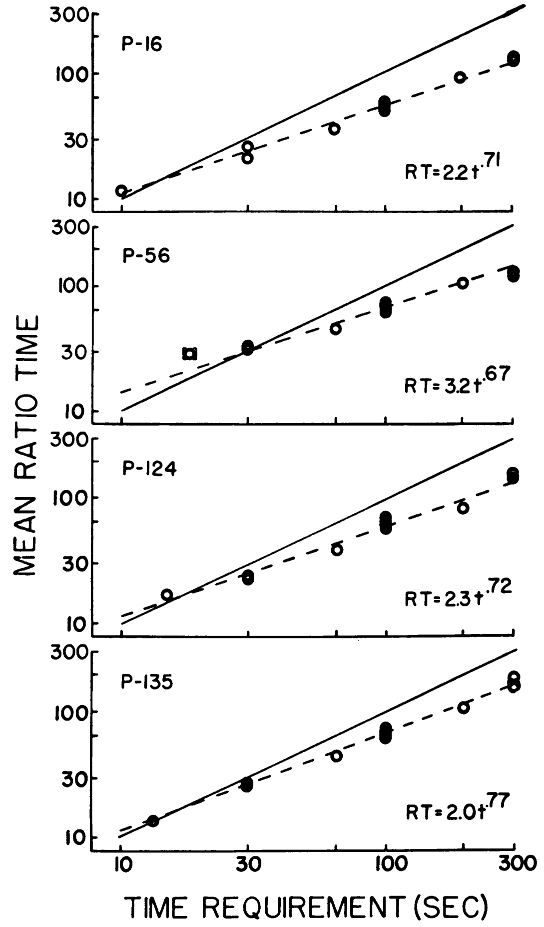

Fig. 5. Ratio time under each requirement. Each point is the mean for the last four sessions of a condition. Details as in Figure 1. The bracketed point for P-56 was not fitted.

replicated each other. Emitted and required times corresponded closely with criteria of 30 sec or less; actually, the emitted times exceeded those required under the shortest criteria. Ratio times increased with requirements longer than 30 sec, but matching no longer occurred. Instead, emitted durations increasingly departed from matching. A power function (dashed lines), fit by the least-squares method, described the performance.

Figure 6 shows frequency distributions of ratio times pooled across replications (Condition 19 excluded), since the distributions did not differ in the various exposures to each requirement. As in Experiment 1, both the means and standard deviations increased as a function of the requirements.

Differentiation With Added Stimulus

Figure 7 shows the mean ratio time and one standard deviation about the mean for the last four sessions of Conditions 3, 4, 5, 6, 7, 8, 14,

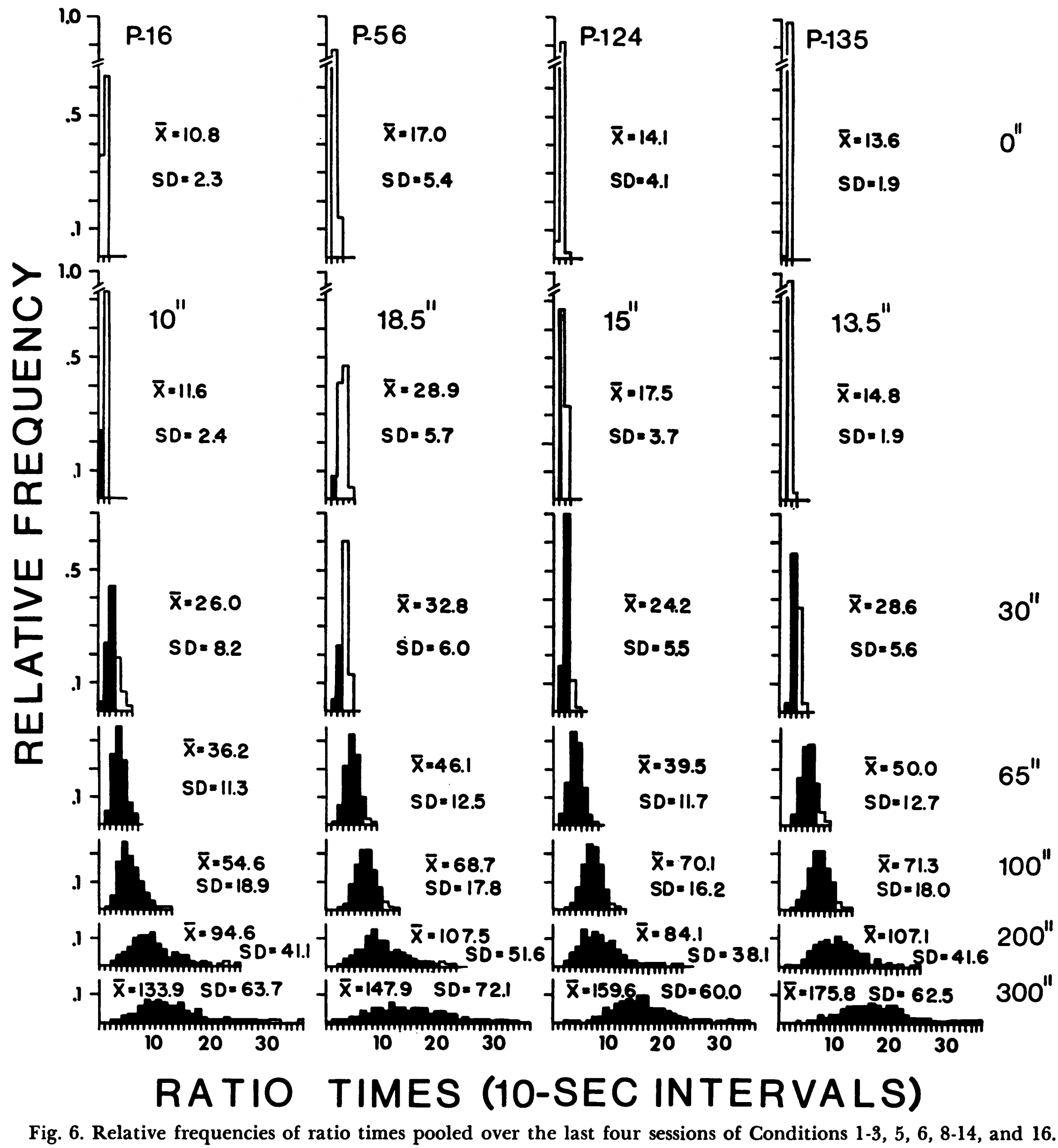

Fig. 6. Relative frequencies of ratio times pooled over the last four sessions of Conditions 1-3, 5, 6, 8-14, and 16. Details as in Figure 3, except that standard deviations were computed from the actual individual ratio times.

15, and 16. These were the conditions involving the key-color change from red to white when the requirement had elapsed, as well as those of the immediately preceding and following no-stimulus-change conditions. Before the stimulus was added, ratio times were variable, and the means were substantially lower than the required times. With the stimulus, ratio times consistently slightly exceeded the requirement. These changes were not maintained when the stimulus was removed. Instead, behavior once again became like that occurring before the stimulus was added. Even when a 100-sec requirement with no stimulus (Condition 16) immediately followed the 200-sec stimulus procedure (Condition 15), there seemed to be no transfer of performance from one to the next. Arranging for the occurrence of long ratio times consistently correlated with food presentation by use of the added stimulus had no obvious effect on performance in the absence of the stimulus.

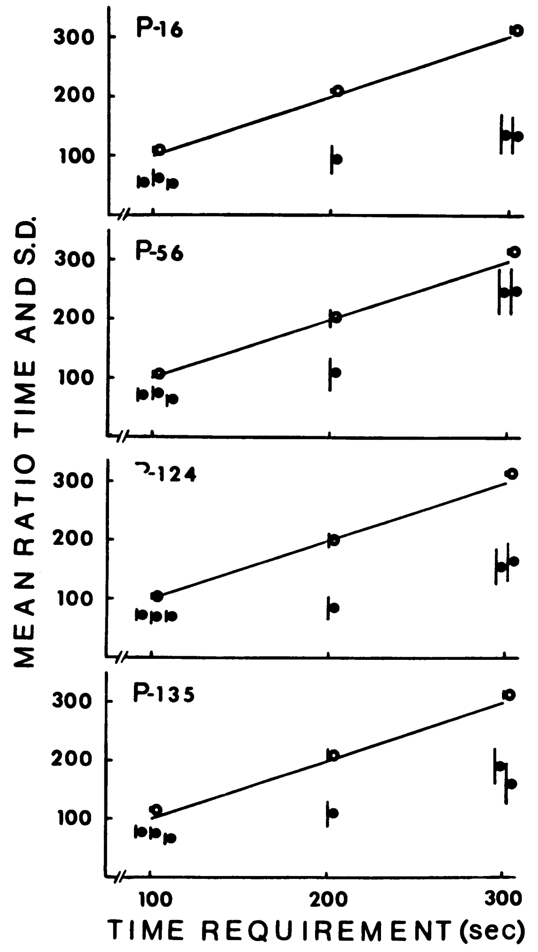

Fig. 7. Mean ratio time (circles) and one standard deviation about the mean (vertical lines) with 100-, 200-, and 300-sec requirements before the stimulus was added (first filled circle), with the stimulus present (open circle), and after the stimulus was removed (second filled circle). The third filled circle at 100 sec occurred after the 200-sec requirement with the added stimulus. If ratio times exactly matched the requirements, they would fall on the solid diagonal line.

Figure 8 shows representative cumulative records for the last session of each condition. Before the stimulus was added, there was an irregular stairstep pattern. With the stimulus, there were two distinctive patterns. The first, shown for P-16, but also occurring with P-135, consisted of no responding while the key was red but responding at a high rate when the key became white. The second, shown for P-124, but also occurring with P-56, consisted of responding at a low rate while the key was red followed by a high rate when the key became white. However, in the 300-sec condition, the patterns of all the birds was like that shown for P-16. When the stimulus then was removed, the irregular stairstep pattern reappeared with all of the birds.

Second-Order Schedules: Reinforcer Density Controls

Condition 16 (100-sec requirement) provided the baseline for the delivery of food in Conditions 17 and 18. In the final four sessions of Condition 16, the number of food presentations per session were 0, 1, 3, and 4 for P-16; 3, 3, 6, and 6 for P-56; 0, 3, 4, and 10 for P-124; 5, 5, 5, and 8 for P-135. In each session, excluding those with no food deliveries, the time between successive presentations and/or between the beginning of the session and the first presentation ranged from 102 sec to 7200 sec; the number of intervening ratios ranged from 1 to 99. Sessions without food presentation were 8144 sec (172 ratios) for P-16 and 10411 sec (170 ratios) for P-124. Over the four sessions combined, the mean interreinforcer interval was 4307 sec (P-16), 1993 sec (P-56), 2928 sec (P-124), and 1618 sec (P-135). The mean number of ratios between successive food presentations was 84 (P-16), 32 (P-56), 43 (P-124), and 25 (P-135).

When these distributions of food presentations were used to establish VI (FR 30) and VR (FR 30) yoked in terms of food presentation density, the obtained densities approxi-

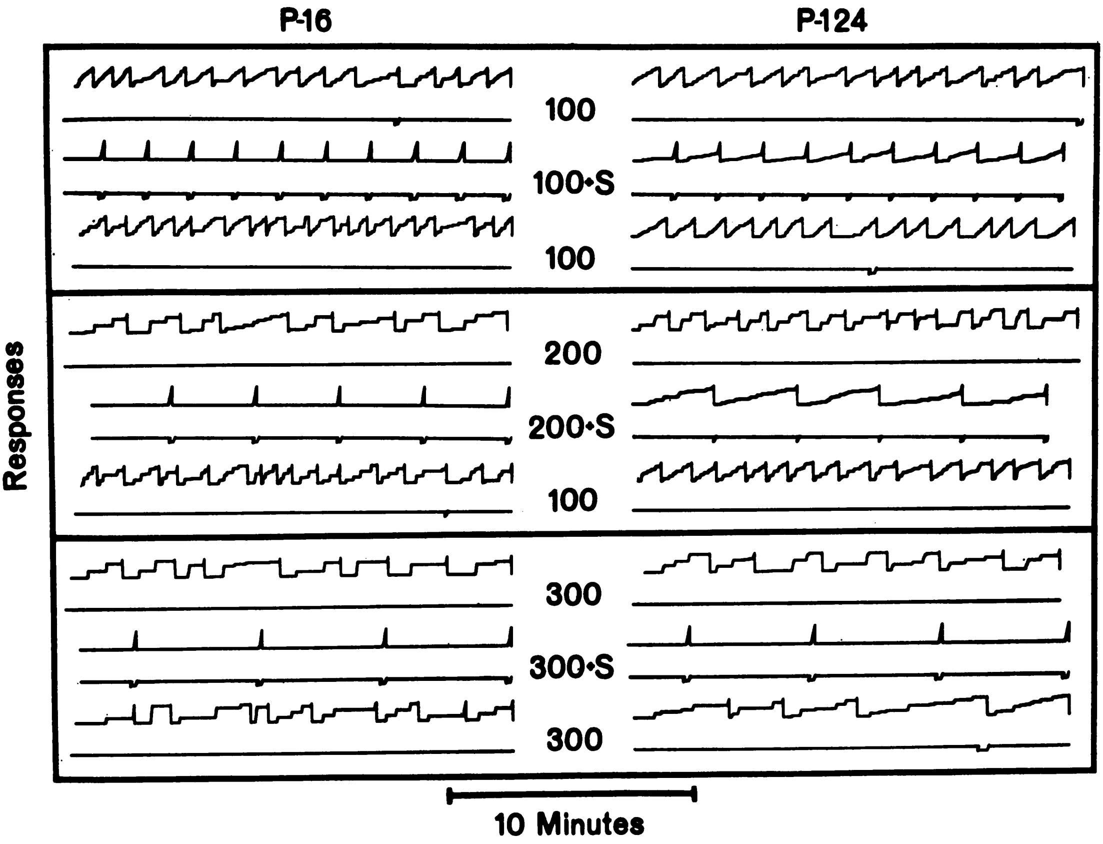

Fig. 8. Segments of cumulative records from the last session before the stimulus was added (top records), while it was present (middle records), and after it was withdrawn (bottom records). The time requirements appear next to each record. The response pen reset after each ratio, and the event pen offset when food was available and reset when it was delivered.

mated those possible for three birds, but decreased for P-56. Because responding slowed, P-56 had a 10 to 15% increase in the time between successive food presentations in the VI (FR 30) schedule of Condition 17. That bird stopped responding altogether after five sessions of the VR (FR 30) schedule of Condition 18. To regenerate responding, the VR value was lowered to 10, and ratios were completed without difficulty. After 10 sessions, the schedule was increased to its former value, and responding stopped once again. Bird P-124 showed progressively longer pauses within each session of the VR (FR 30) schedule; these necessitated ending every session before the number of ratios emitted under the corresponding session of Condition 16 could be completed. Re-introduction of the 100-sec requirement in Condition 19 restored responding in P-56 and P-124.

Frequency distributions are shown in Figure 9. With the initial 100-sec requirement, the distributions were approximately symmetrical for P-56, P-124, and P-135 and positively skewed for P-16. Under the VI (FR 30) schedule, all distributions were positively skewed. The mean ratio time decreased for all but P-56. With the VR (FR 30) schedule, the mean ratio time decreased still more and the distributions were increasingly skewed for all but P-56, the bird that stopped responding altogether. When the 100-sec requirement was then imposed once again, the initial distributions were recovered for P-56 and P-135, whereas that for P-16 resembled that occurring with the VI (FR 30) schedule, and that for P-124 had more short durations than previously.

The patterns of responding differed under the various conditions. Figure 10 shows cumu-

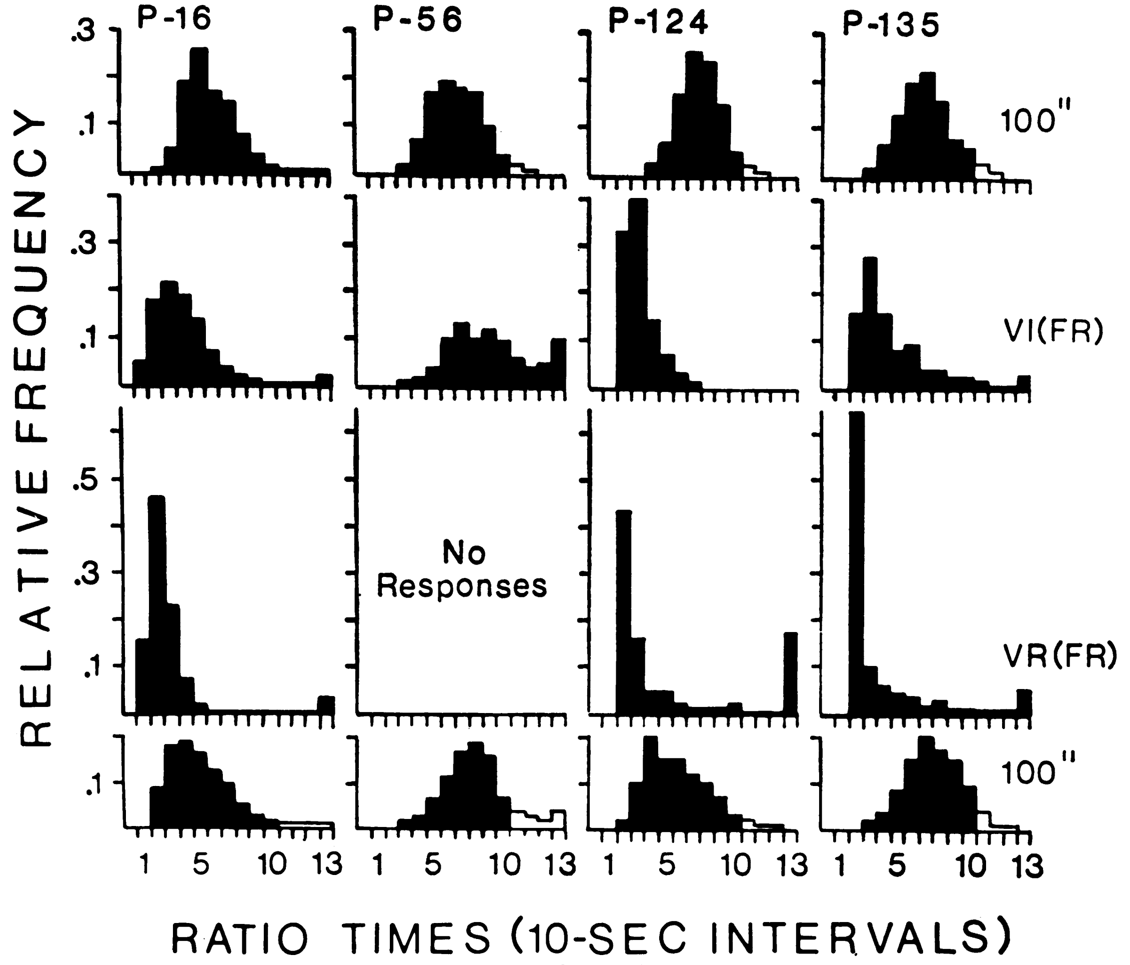

Fig. 9. Relative frequencies of ratio times occurring during the last four sessions of the 100-sec requirement (Condition 16), the yoked VI (FR 30) (Condition 17) and VR (FR 30) (Condition 18) schedules, and the succeeding 100-sec requirement (Condition 19). Details as in Figure 4.

lative records taken from the last session of each condition for P-135. These records are representative of those for all birds (whenever responding was maintained). Under the 100-sec requirement before the VI (FR 30) and VR (FR 30) schedules, groups of responses were separated by pauses. Under the VI (FR 30) schedule, each ratio began with a pause followed by a steady response rate. This pattern remained under the VR (FR 30) schedules, but pauses typically were shorter and the postpause response rate higher than had occurred with the VI (FR 30) schedule. When the 100-sec requirement was re-imposed, P-56 and P-135 continued to show the patterns observed under the second-order schedules: a pause followed by a steady rate of responding. Birds P-16 and P-124 also showed that pattern, but there also were ratios emitted according to the previous irregular stairstep pattern. The recoverability of ratio time for P-56 and P-135, but not pattern, implies that different variables are responsible for the duration of the sequence and the way the component events enter into the sequence.

GENERAL DISCUSSION

In Experiment 1, no stimulus event followed ratios having a shorter duration than that specified. In Experiment 2, a stimulus change followed all ratios. Despite the procedural difference, the emitted durations consistently exceeded the shortest requirements, approximately matched the middle range, and progressively departed from matching with still longer durations.

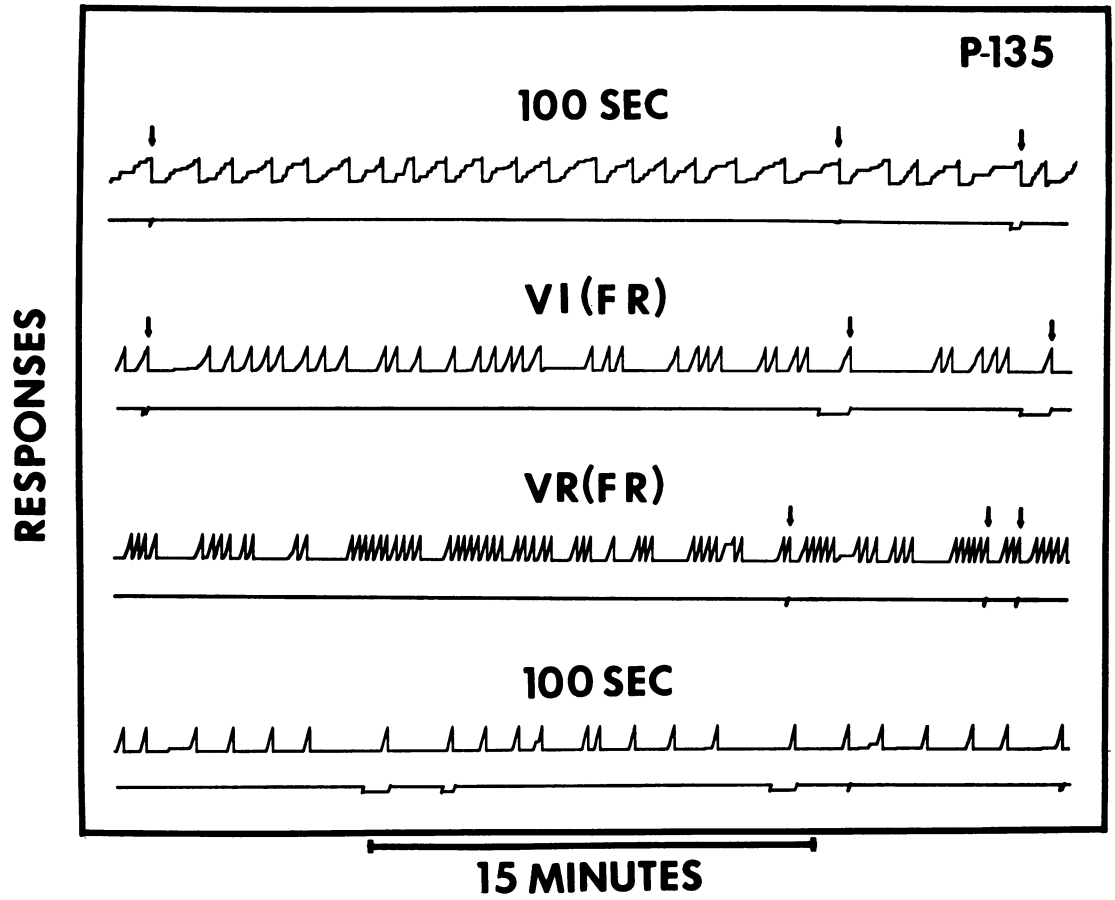

Fig. 10. Cumulative records for the last session with the 100-sec requirement and the two second-order schedules for P-135. Arrows indicate a food presentation with the 100-sec requirement and the corresponding location during the second-order schedules. Other details as in Figure 8.

Quantitative analyses showed correspondences not only among these data but between them and results obtained with differentiation of response latency (Catania, 1970), and the duration of individual responses (Platt *et al.*, 1973). All of these data could be described by a power function, $T = kt^n$, where T and t are the emitted and required times respectively, and k and n are empirically determined values. Only those data that permitted description by the power function were actually fitted, because there seemed to be good reason for excluding the others. Divergences occurred either with the shortest or the longest values. The duration emitted when there is no requirement (the base duration) determines how short a requirement actually can make contact with behavior. Therefore, it is predictable that performance would not change with still shorter requirements, and these should be omitted from a quantitative analysis. Catania (1970) found an upper limit on latency requirements beyond which performance becomes erratic and poorly maintained. He suggested that such conditions probably also should be excluded from a quantitative analysis, because they are likely to stem not directly from the time requirement, but from other factors.

Given these limitations, each subject's performance could be described with k between 1.1 and 3.3 and n between 0.67 and 0.98. The small ranges of k and n needed to encompass all of the data led to the attempt to fit the various results with a single function. The time requirements that exceeded the base duration and yielded orderly data were 0.8, 1.6, 3.2, and 6.4 sec (Platt *et al.*, 1973); 1.27, 2.75, 5.15, 7.5, 10.0, 14.9, 24.4, and 36.4 sec (Catania, 1970); 16, 30, 50, 75, and 100 sec (Experiment 1); and

30, 65, 100, 200, and 300 sec (Experiment 2). Although Platt *et al.* reported median response duration and Catania presented mean latency, individual data were estimated from the power functions given for each subject. Figure 11 shows the relation between the individual performances and the requirements in these experiments together with those of Experiments 1 and 2. The equation, $T = 1.5t^{0.82}$, provided a reasonable fit to all of the points.

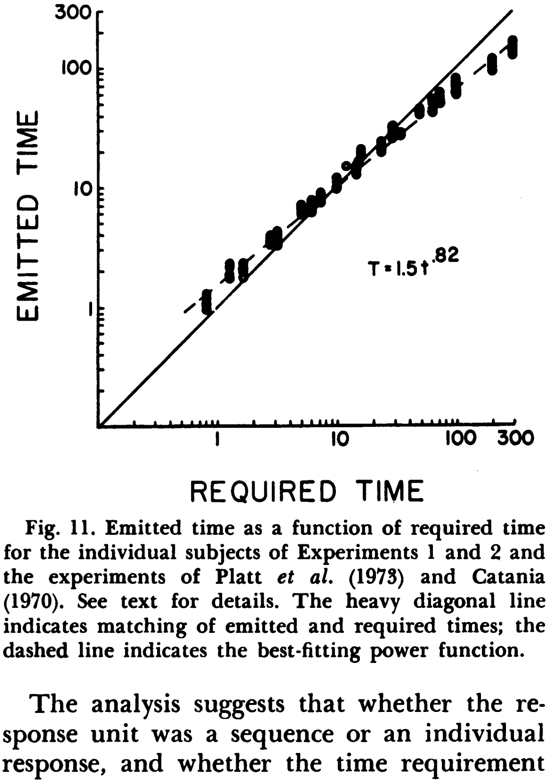

Fig. 11. Emitted time as a function of required time for the individual subjects of Experiments 1 and 2 and the experiments of Platt *et al.* (1973) and Catania (1970). See text for details. The heavy diagonal line indicates matching of emitted and required times; the dashed line indicates the best-fitting power function.

The analysis suggests that whether the response unit was a sequence or an individual response, and whether the time requirement was a duration or a latency, one function could describe the data. The procedures do differ in how short a requirement may contact behavior and perhaps in how long a one may maintain orderly performance, but between these endpoints, all generate quantitatively equivalent functions. The present data conform to Catania's (1970) observation that a variety of temporal differentiation procedures produces similar effects.

There was an inverse relation between k (the intercept of the function) and n (the slope). Overall, the correlation coefficient (r) between the pairs of k and n generated by each subject (17 in all) was -0.90. Thus, it seems that the values of the two parameters are not independent. The significance of this observation is at present unclear.

Variability in responding varied systematically with the requirements in the four experiments. Catania (1970) observed that the relative standard deviation, that is, the ratio of the standard deviation to the mean, was approximately constant at 0.30 over the entire range of required latencies. Platt *et al.* (1973) computed an analogous statistic and found it to be equivalent to a relative standard deviation of about 0.30. In the present Experiment 1, the relative standard deviation averaged across birds for each time requirement ranged from 0.18 to 0.28; in Experiment 2, it ranged from 0.23 to 0.47. These relations between central tendency and dispersion further imply the similarity of the effects of temporal differentiation schedules on different response units.

The distributions of ratio times occurring with the differentiation procedure were not the same as those controlled by comparable densities of food presentation in the absence of duration requirements. Schedules yoked to either the time or the number of ratios between successive food presentations either produced shorter ratio times than did the differentiation schedules or sustained responding less well. Two aspects of the differentiation schedules perhaps were responsible for these differences. The first is that the correlation between particular ratio times and the reinforcing stimulus is the crucial determinant of the precise durations of the fixed-ratio sequence in the differentiation procedures. This operates to change the ratio times in the direction of the requirements. With no time requirement, intermittent reinforcement of the simple fixed-ratio performance was characterized by short ratio times. The second aspect is that whenever the tendency to respond weakens in the differentiation condition, a long ratio time results and responding is regenerated. This correlation is not built in to VR (FR 30) schedules, because in those, food presentation always requires the emission of a certain number of ratios. The schedule does not arrange to have food presentation occur when it is needed to revive poorly maintained performance. The VI (FR 30) schedule does have regenerating characteristics, since the availability of a reinforcer becomes increasingly likely as time elapses. Thus, the variable-interval schedule was able to maintain responding when the variable-ratio schedule could not.

Differences in the effects of differentiation and intermittent reinforcement procedures also occur in the context of single responses. Richardson (1973) investigated whether the interresponse-time distribution obtained when a 15-sec interresponse time was required would be maintained when the requirement was removed but the temporal distribution of food presentations was maintained by a variable-interval schedule. Under the variable-interval schedules, the modal interresponse times were less than with the differentiation procedure, and the shapes of the distributions changed from approximate symmetry toward positive skewness. Furthermore, Alleman and Platt (1973) showed that the differentiation of interresponse times has specific effects that cannot be attributed to the number of responses per reinforcer presentation.

Experiment 2 showed that adding a stimulus correlated with the duration requirement produced ratio times that slightly exceeded the requirement, whereas without the stimulus, mean ratio times were less than required and individual ratio times varied considerably. With no stimulus, the keylight was red regardless of whether the ratio ended with food or with a timeout. Therefore, only appropriate ratio times were differentially correlated with food presentation; no exteroceptive stimuli had this relation. Given that the effect of a reinforcing stimulus is to increase the probability of the behavior that precedes it, the relation between ratio time and the time requirements occurred because of the correlation between the reinforcing event and the durations of completed fixed ratios. With the stimulus, however, food appeared only when the key was white. Thus, red became a discriminative stimulus correlated with the absence of food, and responding was suppressed. However, since the occurrence of some responding in the presence of such a stimulus is not uncommon (*cf.* Morse, 1955), it is not surprising that two of the birds did respond during red under some conditions. In contrast, white became a discriminative stimulus correlated with food presentation according to an FR 30 or lower ratio schedule, and responses were emitted at a high rate when it appeared. The matching of ratio time to the requirements probably resulted from this stimulus control of responding and had little to do with the differentiation of long ratio durations.

The effects were analogous to those involving the addition of stimuli to interresponse-time differentiation schedules (McMillan, 1969; Reynolds, 1966; Reynolds and Limpo, 1968) and to individual response-duration schedules (Stevenson and Clayton, 1970). Stimuli signalling when required time has elapsed can bring the temporal characteristics of either single responses or entire fixed-ratio sequences under precise control. Once again, it appears that variables determining temporal properties of behavior operate independently of the particular response unit involved.

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