

TIME LIMITS FOR COMPLETING FIXED RATIOS.
IV. COMPONENTS OF THE RATIO¹

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Pigeons received food after completing a fixed ratio if the temporal properties of responding exceeded minimum duration requirements. In one set of conditions, a minimum time had to elapse before the first response of the ratio (the initial pause). In another set, the minimum duration was the time between the first and last response of the ratio. Obtained times increased as a power function of required times in both conditions. The power function resembled that occurring in experiments involving temporal differentiation of individual responses, interresponse times, latencies, and entire fixed-ratio sequences. Moreover, in all of these experiments individual performances could be described as a function of the base duration (the duration occurring in the absence of temporal requirements) and the specific time requirement. Control conditions indicated that the effects resulted from temporal requirements and not from reinforcer intermittency.

Key words: fixed-ratio schedule, temporal differentiation, postreinforcement pause, run time, quantitative analysis, base duration, key peck, pigeons

Temporal differentiation schedules specify that reinforcing stimuli follow responses having specified durations. Each particular version prescribes the response unit (*e.g.*, an individual response or response sequence), the property to be differentiated (*e.g.*, the response or sequence duration, interresponse time, *etc.*), and the nature of the requirement (*e.g.*, minimum or maximum duration). With minimum requirements placed on the duration of individual responses (Platt, Kuch, and Bitgood, 1973), latency (Catania, 1970), interresponse time (Malott and Cumming, 1964), or on the total time taken to complete a fixed ratio (DeCasper and Zeiler, 1974), performances displayed substantial similarity. Behavior was described by the power function, $T = kt^n$, where T was the obtained duration of the property, t was the required duration, and k and n were empirically determined constants. Similarities in k and n across the experiments suggested that the effects of temporal differentiation

schedules were independent of the particular response units or temporal properties.

The research involving fixed-ratio schedules indicated that either the time to the first response, the time between the first and last responses, or both might change when requirements involved their sum. The present experiment imposed temporal requirements directly on the components to determine whether their functional relation to the time requirements is similar to those found with total ratio times and individual responses.

METHOD

Subjects

Six White Carneaux pigeons were maintained at 80% of their free-feeding weights. Birds P-103 and P-113 had previous exposure to a variety of reinforcement schedules, P-16 and P-135 had experience with ratio-time differentiation schedules, and P-145 and P-147 were experimentally naive.

Apparatus

The experimental chamber was illuminated by 1-W white lamps located in the upper corners of the response panel. A 1.9-cm diameter response key (R. Gerbrands Co.), activated by a minimum force of 0.18 N, was centered 24 cm

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from the floor. The key could be transilluminated by either two 1-W green or two 1-W red lamps. A relay behind the panel operated by each response provided auditory feedback when the key was green. A 5-cm square aperture centered 10 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 lamp and all other illumination was off. Continuous white noise masked extraneous sounds.

Procedure

Sessions were conducted seven days per week. Each lasted for 20 food presentations or 125 ratios, whichever occurred first.

Differentiation of pause time. For P-113, P-135, and P-147, if the time between the onset of the green keylight and the first response exceeded a specified time (t), the thirtieth response was followed by food presentation. If the first response occurred before t sec elapsed, the thirtieth response produced a 4-sec change in key color from green to red. Responding while the key was red had no scheduled consequence. Thus, the schedule was an FR 30 with differential reinforcement of the initial pause duration. After food or red-key presentation the key became green again, thereby signalling the beginning of the next opportunity to respond.

After exposure to a simple FR 30 schedule ($t = 0$ sec), each subject encountered pause requirements of 5, 10, 20, 40, and 80 sec, but in a different order. One value, different for each subject, was studied twice to examine recoverability of performance. The order and number

of sessions at each requirement are shown in Table 1 (Conditions 1 to 7).

Each condition was maintained until performance met a stability criterion involving the mean pause time for each session. The median of successive groups of three means was computed. A condition continued until three consecutive medians (based on nine consecutive sessions) neither increased nor decreased monotonically.

Differentiation of run time. For P-16, P-103, and P-145, the differentiated property was run time rather than pause time. Food presentations followed each ratio only if the time between the first and thirtieth responses exceeded time t . Otherwise, the thirtieth response produced the 4-sec change in key color from green to red.

As in the pause-time conditions, each subject began with a simple FR 30 schedule ($t = 0$ sec). Then, each subject encountered run-time requirements of 20, 40, 60, 80, and 100 sec, but in a different order, and one requirement was re-imposed (Table 1, Conditions 1 to 7). The criteria for changing conditions were as described above but with run time considered, rather than pause time.

Yoked reinforcer-density controls. In any differentiation procedure, the intermittency of reinforcement depends on the accuracy of performance: reinforcer presentations can, but may not, follow every unit of behavior. Conditions 7 to 10 involved controls for intermittent reinforcement arising as a consequence of inaccurate differentiation performance. Separate conditions controlled for the effects of reinforcer intermittency in time and in the number of ratios between food presentations. For

Table 1
Order of Experimental Conditions and Number of Sessions at Each for Each Subject

Order	Pause Time > t						Run Time > t					
	P-113		P-135		P-147		P-16		P-103		P-145	
	Cond.	Sess.	Cond.	Sess.	Cond.	Sess.	Cond.	Sess.	Cond.	Sess.	Cond.	Sess.
1	0	24	0	24	0	25	0	25	0	25	0	25
2	20	20	80	17	5	18	20	18	60	17	100	19
3	5	14	20	14	40	23	100	22	20	13	40	17
4	10	15	10	12	5	12	20	19	80	16	60	21
5	20	17	40	12	80	24	40	15	60	19	20	15
6	80	24	5	19	20	17	80	21	40	11	100	16
7	40	19	80	14	10	14	60	18	100	10	80	16
8	VR 42	24	VR 25	26	VI 1-min	12	VI 58-min	13	VR 57	42	VR 27	19
9	VI 19-min	20	VI 26-min	13	VR 3	11	VR 59	21	VI 69-min	17	VI 27-min	14
10	40	21	80	19	10	12	60	37	100	18	80	34

the time control, the obtained interfood intervals in the last six sessions of Condition 7 were used to arrange six VI(FR 30) second-order schedules. Thus, there were six separate sequences of interfood intervals. Each session or sequence of the time-control condition was yoked to one of the six sessions of Condition 7. When the same interreinforcement time had elapsed, the next completed ratio was followed by a darkened key and food presentation. All other ratios were followed by the 4-sec change in key color from green to red. For the ratio-number control, the number of ratios separating successive food presentations during each of the last six sessions of Condition 7 were used to arrange six VR(FR 30) schedules. Food presentations followed the appropriate number of ratios. All other ratios were followed by the red key. In both controls (Conditions 8 and 9), each of the six schedules occurred ran-

domly within blocks of six sessions. The average interreinforcement interval (VI value) and average number of ratios per food presentation (VR value) are shown in Table 1. Sessions lasted for as long (VI) or for as many ratios (VR) as did the differentiation sessions to which they were yoked.

Condition 10 re-imposed the requirements of Condition 7. The purpose was to determine whether differentiation effects were recoverable after the interpolated history with intermittent reinforcement of fixed-ratio performance involving no time requirements.

RESULTS

Differentiation of Pause Time and Run Time

All analyses were based on pause and run times of the last three sessions of each condition (or enough sessions to have at least 100

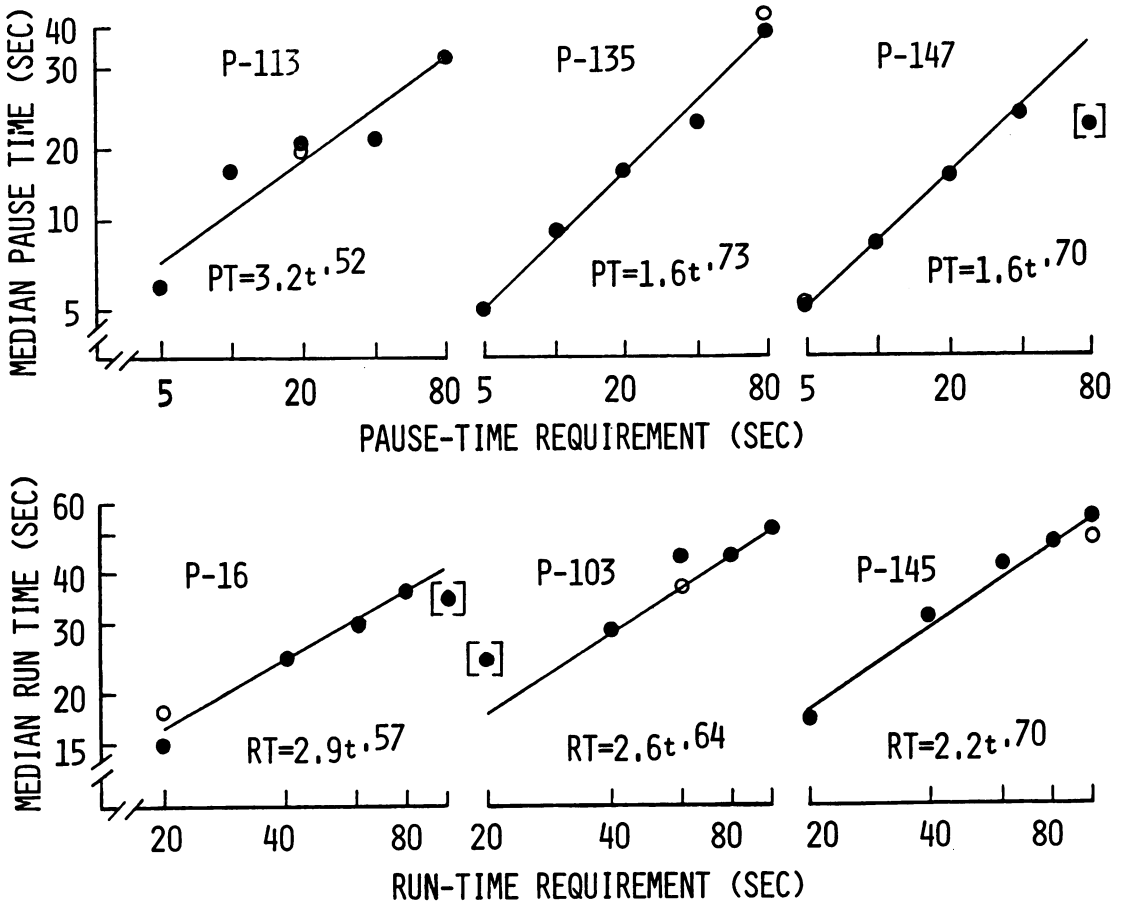


Fig. 1. Median pause and run times from Conditions 2 to 7 as a function of their respective requirements in logarithmic coordinates. The lines represent power functions, shown for each subject, fitted to the medians. The bracketed points were not fitted (see text). Redetermined points appear as unfilled circles.

times). Figure 1 shows the power functions relating pause times and run times to their requirements for Conditions 2 to 7. For P-16 and P-147, the longest requirement was excluded, because cumulative records and frequency distributions (Figure 2) indicated that the charac-

ter of performance differed in kind from that of the other conditions. The low reinforcer densities encountered at the longest time requirements may result in diminished sensitivity to duration requirements (*cf.* Catania, 1970; DeCasper and Zeiler, 1974). Deviation

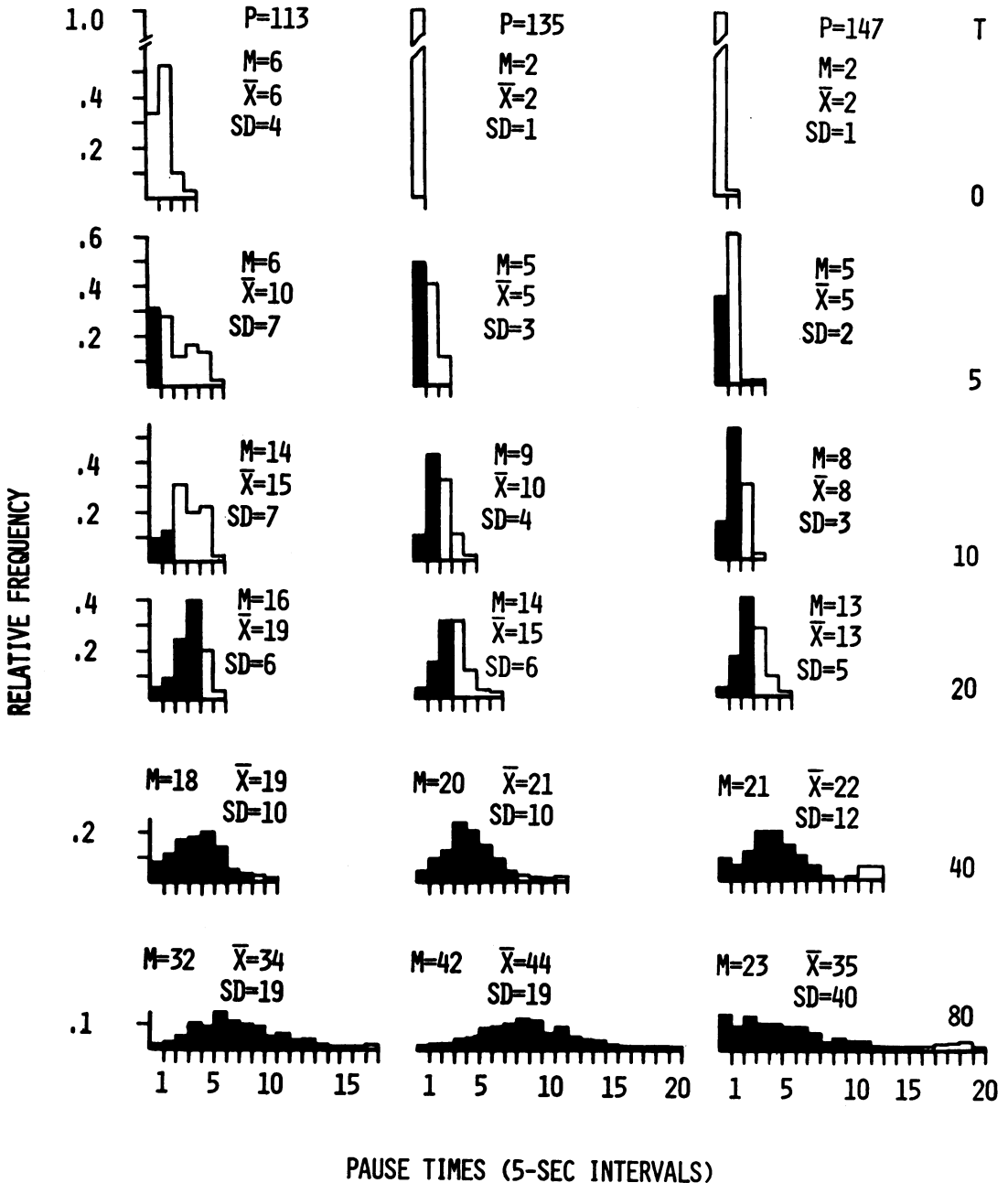


Fig. 2. Relative frequency, median, mean, and standard deviation of pause and run times at their respective requirements in Conditions 1 to 7. The unshaded areas indicate reinforced ratios. Data from replicated requirements were pooled.

from an otherwise orderly function perhaps is evidence for such transitions. For P-103, the 20-sec point was also omitted; without this point, the variance about the best-fitting function was 0.70; with it included, the variance was 3.50. The shortest time requirements may provide equivocal information in any case, be-

cause they may contact behavior infrequently. Once again, deviations from an otherwise simple function may index control by other factors.

Figure 2 shows frequency distributions of pause or run times, as well as medians, means, and standard deviations for Conditions 1 to 7.

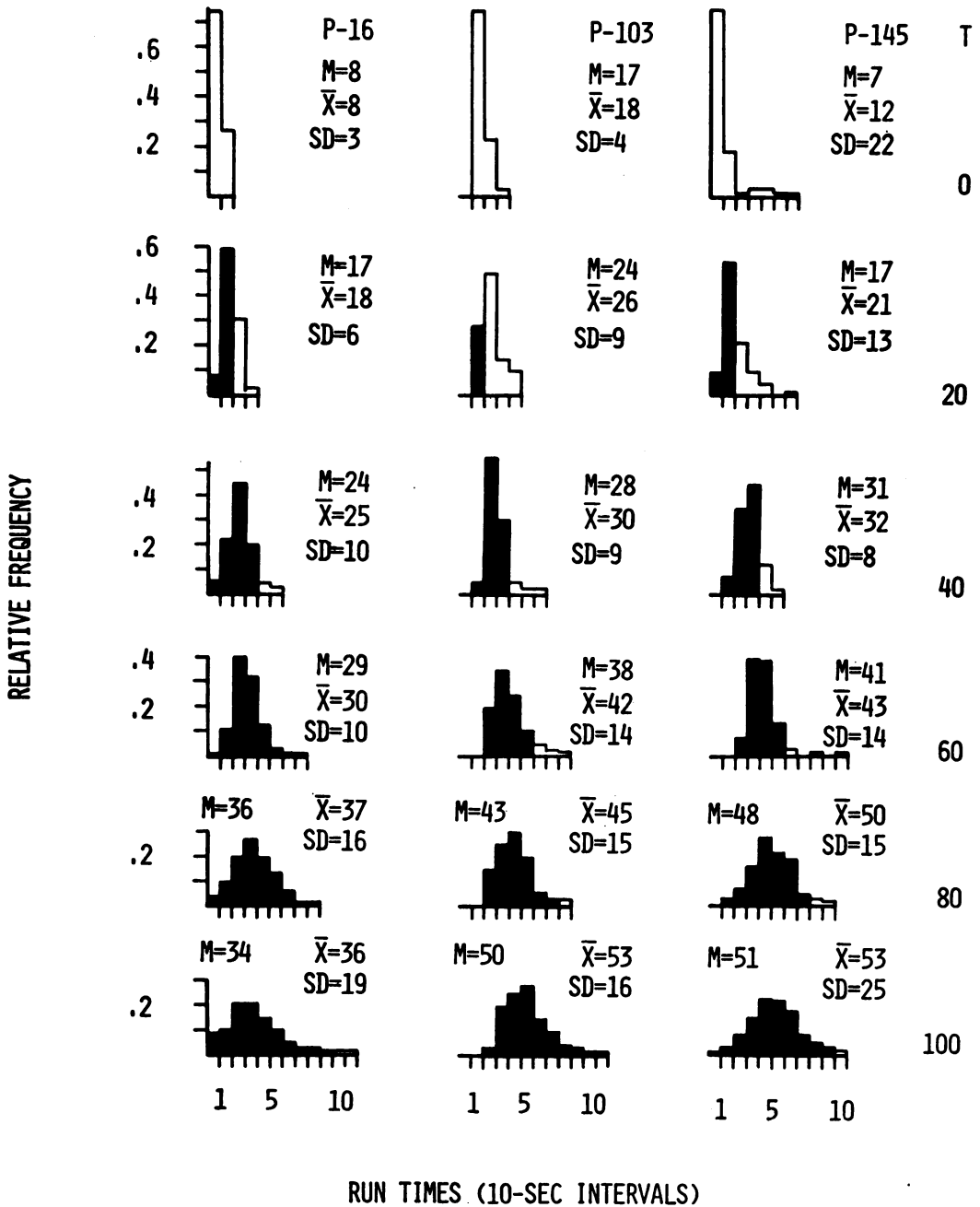


Figure 2—Continued

Since performances were recovered when requirements were repeated, the separate conditions were combined. Mean, median, and modal times increased with longer requirements, but the proportion of ratios having sufficiently long pause or run times to end with food presentations decreased. Variability increased along with the means. For all but three cases, the ratio of the standard deviation to the mean (the relative standard deviation or the coefficient of variation) ranged between 0.25 and 0.56.

Figure 3 shows segments of cumulative records of P-135 and P-145 for the last session at

each time requirement. These records were characteristic of the other birds as well. With no time requirement ($t = 0$ sec), a brief pause was followed by 30 responses emitted at a steady rate. With progressively more stringent pause-time requirements (P-135), pauses lengthened but the pattern was preserved. With run-time requirements (P-145), the pattern became increasingly irregular.

Figure 4 shows how the noncriterion property of performance was related to the time requirements. Different pause-time requirements had no effect on median run times. With run-time requirements, some pause-times changed, but not in a simple manner.

Yoked Reinforcer Density Controls

Figure 5 indicates that pause and run times maintained by the differentiation conditions were not preserved by the yoked VI(FR 30) and VR(FR 30) second-order schedules. The distributions changed from approximately symmetrical to positively skewed. Median

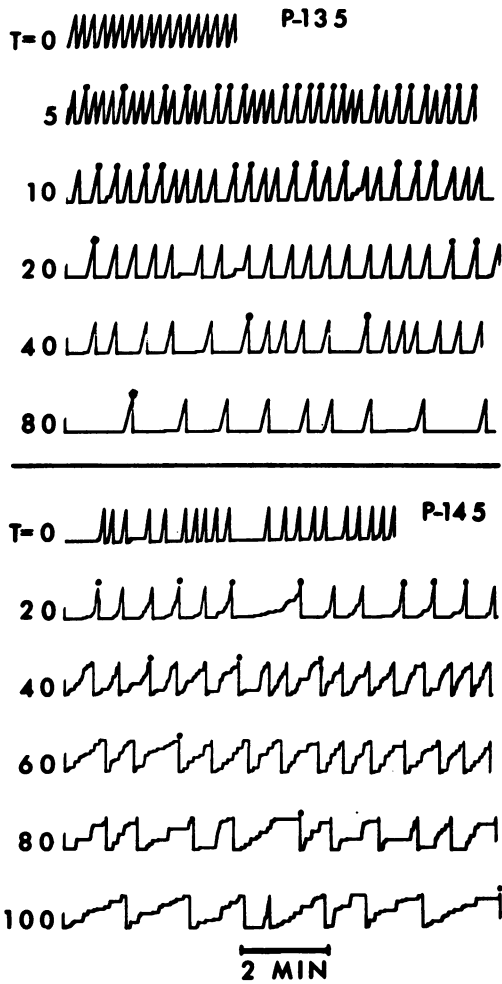


Fig. 3. Segments of the cumulative records from the terminal session of each pause time (P-135) and run time (P-145) requirement in Conditions 1 to 7. The response pen reset after each FR 30. Food followed each ratio with the 0-sec requirement and those marked by a dot: all other ratios were followed by a 4-sec time-out.

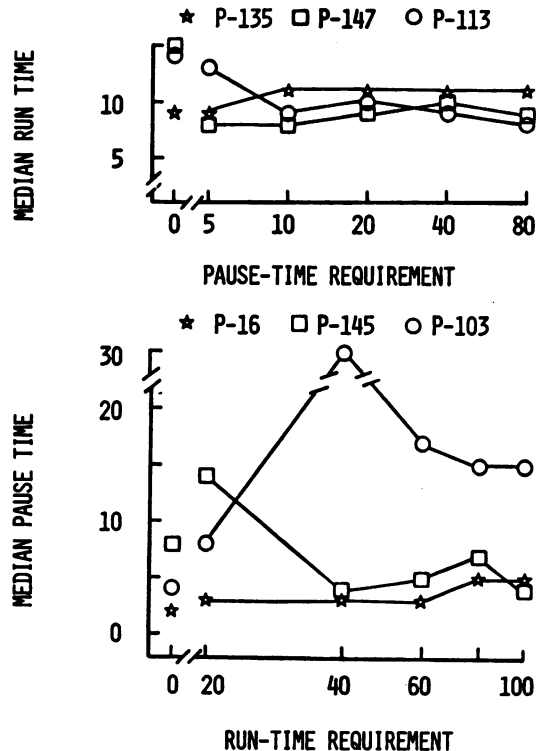


Fig. 4. Median run times occurring with the pause-time requirements and median pause times occurring with the run-time requirements of Conditions 1 to 7. The unconnected points are medians occurring with the simple FR 30 schedule. Time requirements are on a logarithmic scale for ease of presentation.

pause duration decreased for the pause-time conditions and, except for P-103, median run times decreased for the run-time conditions. Instead of recovering the performances of Condition 7, Condition 10 produced distributions that had higher relative frequencies of short times and/or were positively skewed. These often more closely resembled the distributions established by the interpolated second-order schedules.

DISCUSSION

The criterion for a conditionable behavioral unit is that its probability of occurrence varies lawfully depending on its consequences. Pause and run time each defined a conditionable unit. In every case, orderly effects occurred with respect to the specified property of the ratio.

Frequency of reinforcement in time (inter-reinforcer time) has been implicated as a de-

terminant of the initial pause in fixed-ratio schedules. When interreinforcer time has been increased, initial pause has increased as well (Crossman, Heaps, Nunes, and Alferink, 1974; Neuringer and Schneider, 1968). The present procedures also restricted interreinforcer times: maximum reinforcement frequency was determined by the time requirements. If either pause-time or response rate after the pause (running rate) was a function of reinforcement frequency, pause durations should have lengthened when run-time requirements were increased and running rate should have changed along with pause-time requirements. Since neither occurred, to a considerable extent pause time and running rate were independent of interreinforcer time.

Steady-state performance in simple fixed-ratio schedules reveals stereotypy in both pause and run time (e.g., Ferster and Skinner, 1957). Because either is conditionable, this could arise from adventitious relations between

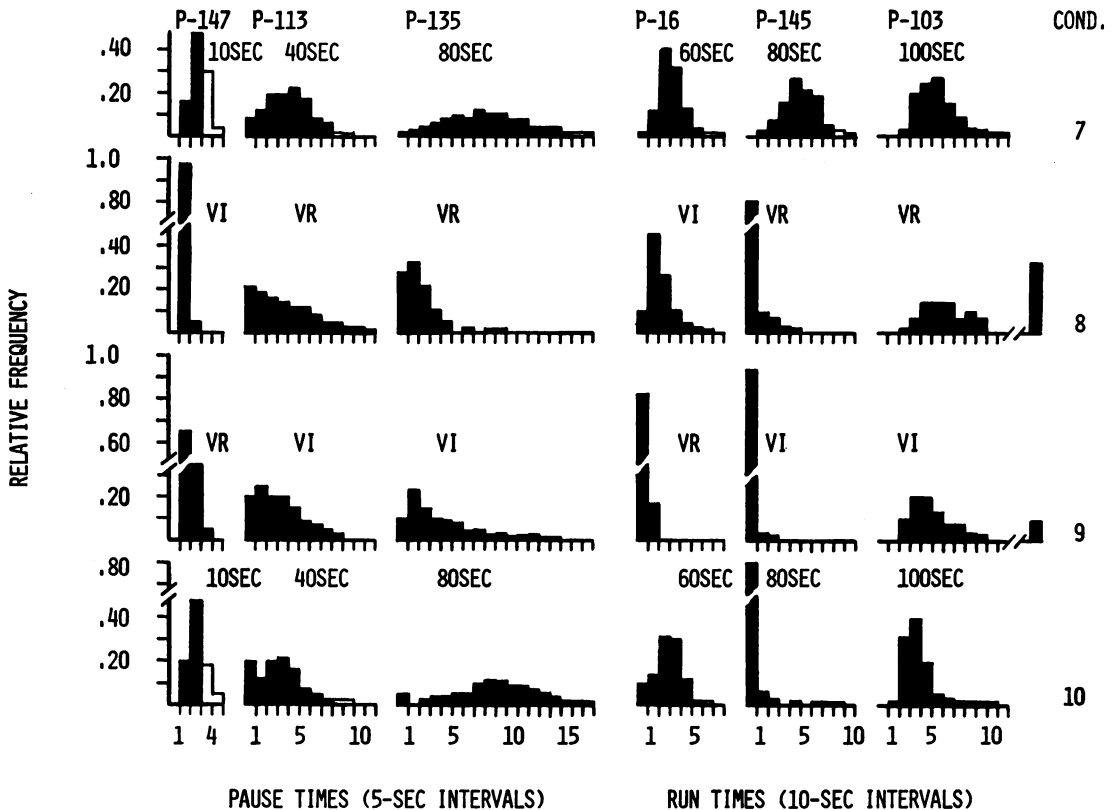


Fig. 5. Relative frequency of pause and run times with their respective requirements (Conditions 7 and 10) and the interpolated variable-ratio and variable-interval schedules (Conditions 8 and 9). The unshaded areas indicate reinforced ratios with the time requirements.

pause and run-time durations and the reinforcing stimulus. If this was the case, the durations most frequently followed by the reinforcer should continue to occur. In fact, the pause times that predominate in early exposure to fixed-ratio schedules do become still more probable with prolonged exposure (Zeiler, *in press*), an effect supporting the hypothesis that whatever pauses are emitted become more probable in the future. Run times, however, have not revealed similar relations. Even though long run times may be most often correlated with reinforcement early in training, shorter run times predominate later (Zeiler, *in press*). These observations suggest that particular pause times may be adventitiously reinforced in ordinary fixed-ratio schedules, whereas the response rate after the pause is determined by other factors.

Neither in this study nor in others (DeCasper and Zeiler, 1974; Richardson, 1973) could the systematic effects of temporal differentiation schedules be attributed to reinforcer intermittency arising because every instance of performance failed to conform to the criterion. Instead, the correlation between specific dura-

tions and food presentations determined the temporal properties of behavior, at least until a history of intermittent reinforcement without respect to response-duration modulated subsequent effects of the temporal requirements (*cf.* DeCasper and Zeiler, 1974). Why a history of intermittency should exert these effects is unclear, but it is a further example of how intermittent reinforcement can establish very durable behavior.

Quantitative Analysis: Base Duration

Column *iv* of Table 2 shows the best-fitting power functions for each subject in experiments on response latencies (Catania, 1970), response durations (Platt, Kuch, and Bitgood, 1973), total ratio time (DeCasper and Zeiler, 1974), and pause and run times in fixed-ratio schedules (present experiment). DeCasper and Zeiler (1974) found that the power function, $T = 1.5t^{0.82}$, approximated the grouped data for the earlier experiments. When the present data were added, the best-fitting function remained the same. Table 2 shows, however, that this function does not correspond to those of the individual subjects.

Table 2
Temporal Differentiation Data Described by Power Functions

<i>i</i> Experiment	<i>ii</i> Temporal Property	<i>iii</i> Subject	<i>iv</i> $T = kt^n$	<i>v</i> Base Duration	<i>vi</i> Equation 1
Platt, Kuch, and Bitgood (1973)	response duration	R-7	$1.23t^{0.88}$	0.14	$1.18t^{0.91}$
		R-9	$1.13t^{0.93}$	0.14	$1.18t^{0.91}$
		R-8	$1.50t^{0.88}$	0.21	$1.26t^{0.89}$
		R-6	$1.45t^{0.82}$	0.25	$1.30t^{0.88}$
		R-10	$1.39t^{0.93}$	0.27	$1.32t^{0.88}$
Catania (1970)	response latency	P-404	$1.4t^{0.88}$	1.3	$1.72t^{0.80}$
		P-402	$1.8t^{0.78}$	1.6	$1.79t^{0.70}$
		P-403	$1.5t^{0.90}$	1.7	$1.80t^{0.78}$
		P-401	$1.9t^{0.88}$	1.8	$1.82t^{0.78}$
<i>Present Data</i>					
PT > t	FR 30 pause time	P-147	$1.6t^{0.78}$	2.0	$1.85t^{0.77}$
		P-135	$1.6t^{0.70}$	2.0	$1.85t^{0.77}$
		P-113	$3.2t^{0.62}$	6.0	$2.23t^{0.71}$
RT > t	FR 30 run time	P-145	$2.20t^{0.70}$	7.0	$2.29t^{0.71}$
		P-16	$2.90t^{0.67}$	8.0	$2.35t^{0.70}$
		P-103	$2.60t^{0.64}$	17.0	$2.67t^{0.68}$
DeCasper and Zeiler (1974)	FR 30 ratio time	P-16	$2.20t^{0.71}$	10.8	$2.47t^{0.60}$
		P-110	$2.20t^{0.75}$	13.3	$2.56t^{0.68}$
		P-135	$2.00t^{0.77}$	13.6	$2.57t^{0.67}$
		P-101	$2.60t^{0.69}$	14.0	$2.58t^{0.67}$
		P-124	$2.30t^{0.72}$	14.1	$2.59t^{0.67}$
		P-56	$3.20t^{0.67}$	17.0	$2.67t^{0.68}$
		P-132	$3.30t^{0.67}$	17.0	$2.67t^{0.68}$
		P-128	$3.10t^{0.67}$	18.9	$2.72t^{0.68}$

The individual functions can be approximated by considering the base duration of the response property. Base duration is the duration in the absence of temporal requirements. For example, the base duration of latency is the latency occurring when every response is reinforced, the base duration of fixed-ratio pause is the pause occurring when every completed ratio produces the reinforcer, *etc.* Base durations (reported or estimated) are shown in column *v* of Table 2. With the table ordered in terms of increasing base duration (*d*), the empirically determined parameters of the power functions, *k* and *n*, increase and decrease respectively.

Linear, logarithmic, power, and exponential equations were fit by the least-squares method to the relation between *d* and *k* and *d* and *n*. A power function, $k = 1.6 d^{0.18}$, accounted for most of the variance between *d* and *k*, and a logarithmic function, $n = 0.82 - 0.12 \log d$, accounted for most of the variance between *d* and *n*. With these expressions for *k* and *n* substituted the power function becomes:

$$T = 1.6 d^{0.18} t^{(0.82 - 0.12 \log d)} \quad (1).$$

Entering each subject's base duration into equation 1 yielded the equations shown in column *vi* of Table 2. For 21 of the 23 subjects, equation 1 more closely approximated the empirically determined *k* values than did 1.5, the value suggested by DeCasper and Zeiler (1974). For 19 of the 23 subjects, the estimate of *n* was closer to the empirically determined value than was the 0.82 proposed by DeCasper and Zeiler.

An alternative function was generated by assuming that time requirements operate relative to base duration. Relative requirements or *t/d* ratios were computed for each subject in Table 2. Approximately equal *t/d* ratios were considered equivalent and grouped together. For 11 groups, a power function, $T = kd^n$, was fit to the relation between *T* and *d*. Thus, 11 values of *k* and *n* were obtained, one for each group or *t/d* value. Then, *k* could be related to *t/d* as $k = 1.7(t/d)^{0.73}$, and *n* to *t/d* as $n = 0.0(t/d) + 0.84$, or $n = 0.84$. Substituting these expressions into the power function and simplifying yields:

$$T = 1.73t^{0.73}d^{0.11} \quad (2).$$

Equation 2 also provided a better fit to the

individual functions than did DeCasper and Zeiler's (1974) account.

Equations 1 and 2 show that an individual subject's behavior can be recovered by incorporating both time requirements and base duration. Base duration is not a free parameter: it is the prevailing duration of the behavior to be differentiated. Incorporating base duration implies that the temporal property of the response unit modulates the effects of differential reinforcement.

When the appropriate value for *d* is substituted into equations 1 and 2, the result is a simple power function of *t* numerically equivalent to those in column *iv*. These temporal differentiation power functions resemble the psychophysical power law. The formal implications of the power law (Stevens, 1957) therefore, also apply to the differentiation functions. As Catania (1970) suggested, this formal similarity may reflect a fundamental relation between temporal differentiation and the psychophysics of time. The continued utility of a power function in describing both the discrimination of duration (*cf.* Eisler, 1975) and the differentiation of response duration perhaps implies that at heart the processes are similar, if not identical.

Base duration may have its counterpart in the discrimination of duration. If the judgment of time intervals is like other psychophysical judgments, the subject's frame of reference for elapsed time is important. The ubiquity of frame of reference in psychophysics has been discussed elsewhere (*cf.* Helson, 1964). Base duration as the subject's "natural response duration" under a given condition is analogous to frame of reference. To the extent that the apparent parallel between temporal differentiation and temporal discrimination is accurate, performance in both represents an interaction of experimenter-imposed time intervals and the subject's temporal referent.

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