

Quantification of pausing on fixed-ratio schedules of reinforcement

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Rat and pigeon data that had been collected in three separate laboratories were examined with reference to the effects on fixed-ratio behavior of either delaying the delivery of a scheduled reinforcer and/or varying the size of the ratio requirement. All such effects were reflected as changes in the duration of the interval (the preratio pause) that intervened between delivery of a reinforcer and commencement of responding for the next one. Although there was considerable variability in the absolute values obtained for the functions, in all cases, and for each individual subject, the relationship between these independent variables and durations of the preratio pause was well described by a power function. This finding is consonant with a previously offered suggestion that power functions provide a useful measurement of response strength for latency-type data.

Some time ago, Ferster and Skinner (1957) observed that fixed-ratio (FR) schedules of reinforcement produce a pattern of responding typified by a pause immediately after delivery of a reinforcer, followed by a steady rate of responding until the next reinforcer. This pattern is found in the behavior of a wide number of species working under FR schedules (Inman & Cheney, 1974; Laursen, 1972; Powell & Curley, 1976; Todd & Cogan, 1978). Subsequent research has confirmed that the pause (usually termed the preratio pause) is remarkably sensitive to a host of independent variables, whereas the responding after it is not (e.g., Felton & Lyon, 1966; Meunier & Starratt, 1979; Morgan, 1972; Powell, 1969; Sidman & Stebbins, 1959).

The purpose of the present work is to suggest a general quantitative rule that seems to serve as a good description of these relationships. Data from one unpublished and two previously published experiments were reanalyzed for this purpose. Only salient methodological details from the previously published experiments are restated in this article.

METHOD

Crossman, Heaps, Nunes, and Alferink (1974, Experiment 1) reinforced pigeons with 3-sec access to Purina Racing Pigeon Checkers according to a two-ply multiple schedule. In the first component, the one of interest to this report, responding according to FR schedules of 25, 50, 100, 200, 300, 25, and 50 was examined in a reversal design. In the other component, the first response after a reinforcer initiated a time-out, and the first response after termination of time-out was reinforced. Both

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birds were experimentally naive at the beginning of the study. Components of the schedule alternated randomly, and an attempt was made to equate average interreinforcement intervals in the two.

Topping, Johnson, and McGlynn (1973), on the other hand, studied eight experimentally naive pigeons in a combined between- and within-subjects design. Four of the birds were maintained at FR 10, two at FR 75, and two at FR 150. Reinforcement consisted of 4-sec access to the food hopper, and different animals were studied at delay-of-reinforcement levels of 0, 10, 30, 60, 90, and 180 sec, with at least one reversal to an earlier delay level for each after presentation of the longest condition. The experimental chamber was darkened during all delay intervals.

The unpublished data from our own laboratory were produced by three male Sprague-Dawley-derived albino rats. Each weighed between 500 and 600 g at the beginning of the experiment and was reduced to 75% of free-feeding weight before data collection began. Water was continuously available in the living cages, and supplementary feeding after each session ensured maintenance of prescribed body weights. Reinforcement in this experiment consisted of 3-sec access to a .05-ml cup of a 53% water, 47% (by volume) Eagle Brand condensed milk mixture and was signaled by a 40-msec presentation of a 2.8-kHz tone. All electromechanical programming and recording equipment was located in an adjacent room. Data were collected in LVE/BRS rodent chambers (Model 143) enclosed in sound-attenuating cases. White noise was continuously provided in the chambers, and illumination was provided by a single GE 1820 lamp enclosed in a jewel cover, which was located 4 cm above the response lever.

The animals were gradually trained to respond on a schedule of FR 18 after magazine training and leverpressing had been established. After stabilization (the absence of any discernible trend in either the cumulative record or preratio pause durations for five consecutive sessions), the animals were shifted to the next ratio according to the order shown in Table 1. This table also shows the number of sessions at each FR level for each animal. Decisions regarding the order of presentation of levels were made by attempting to concurrently assess reliability and strengthen the estimate (by providing additional points) of a goodness-of-fit evaluation. Thus, Subject 8 was exposed, in order, to FR values of 18, 33, 50, 43, and 28. Although performance was never reassessed at a previous level, orders of presentation were staggered, and reliability would be suggested

Table 1
Order of Presentation (P) of Each Ratio Size

Rat	Ratio Size													
	13		18		23		28		33		43		50	
	P	N	P	N	P	N	P	N	P	N	P	N	P	N
8			1	5			5	9	2	9	4	10	3	8
9	4	5	1	23	3	8	2	13						
12			1	16			2	8			3	9	4	10

Note—N = number of sessions at each ratio size.

by the closeness of fit of the obtained data points to a predicted line. The only exception to this strategy was Subject 12, who was injured immediately after he had been studied at FR values of 18, 23, 43, and 50, in that order. His data are included, however, because they do yield information on the fit to a predicted line. Daily sessions were conducted with each subject; a session consisted of the delivery of 50 reinforcers.

RESULTS

After a suggestion by Guilford (1954), each set of data was plotted on logarithmic, semilogarithmic, and linear graph paper in an attempt to find the best-fitting function rule. For all data, this was provided by the logarithmic paper indicating that a power function of the type $P = kR^n$ provided the best fit. In that equation, P represents pause time, R is the independent variable of interest, k is a constant affected by individual characteristics of the organism and the unit of measurement, and n is the slope of the best-fitting line. Following this determination, all variables were converted to logarithmic values (base 10), and the actual value of the lines of best fit and the amount of variability accounted for by them were calculated. The lines were produced by the method of least squares, and the coefficient of determination (r^2) was taken as an indication of the proportion of pause time determined by the independent variable of interest. Although far from a perfect method, in traditional psychophysical work, the decision regarding linearity is typically based on two assumptions: (1) whether the points closely approximate linearity by visual inspection and high product-moment correlation coefficients, and (2) whether any detectable deviations from linearity are systematic (e.g., Painton, Cullinan, & Mencke, 1977; Stevens & Guirao, 1964).

Log-transformed data from the Crossman et al. (1974) study (medians of the last five session medians) are presented as Figure 1. Both sets appear to cluster about the solid lines, which represent their calculated power functions. For Bird 819, the equation $P = .10R^{1.20}$ accounts for 98% of the variability in pausing; for Bird 665, the equation $P = .21R^{1.19}$ accounts for 92%. The similarity of the slopes is striking.

Figure 2 presents the eight sets of data points and corresponding power functions from the Topping et al. (1973) study, grouped according to the values of the FR schedule for the birds. The data are log transformations of the arithmetic mean of the median pause

from each animal's last three sessions at a given delay interval. Data from the 0-sec delay were not utilized in the analysis. Exponents of the best-fitting functions and corresponding r^2 measurements are presented in Table 2. The percentage of variability accounted for by the functions for the two birds at FR 150 is considerably below that found for the others. This would seem to follow from the observation that random variability in pausing increases with increases in interreinforcement intervals (Bullock & Richards, 1973).

An interesting incidental observation concerning these data is that when all possible pairs are considered, the pause time for a replicated observation was briefer on the replication than on the original presentation in 16 out of a possible 19 occasions. This phenomenon was tested with a sign test (Siegel, 1956) and found to be significant at the .05 level. Other experimenters have

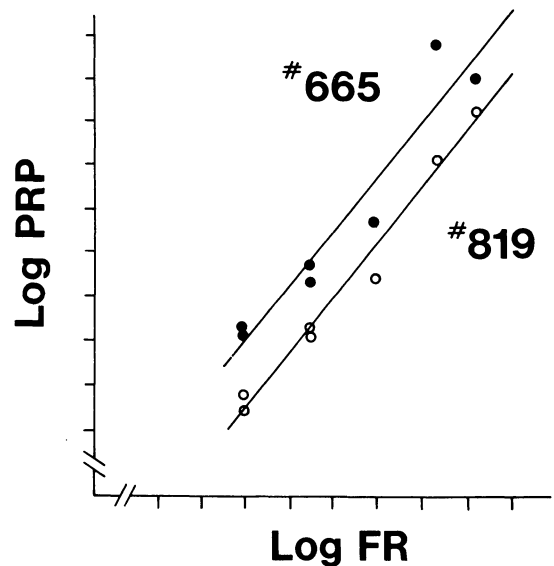


Figure 1. Logarithm of preratio pause as a function of logarithm of ratio size for Bird 819 (open circles) and Bird 665 (closed circles) from Crossman, Heaps, Nunes, and Alferink (1974). Solid lines represent lines of best fit calculated by method of least squares.

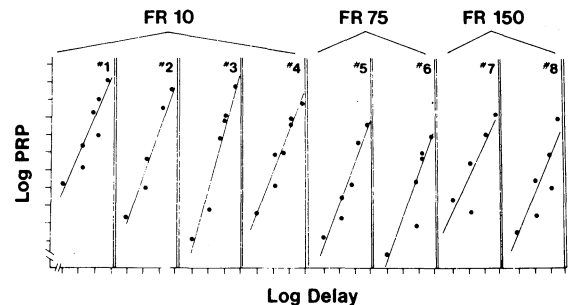


Figure 2. Logarithm of preratio pause as a function of logarithm of delay interval for the eight birds from Topping, Johnson, and McGlynn (1973), grouped according to FR size. Solid lines represent lines of best fit calculated by method of least squares.

Table 2
Values of Exponents and Percentage of Variance Accounted for (r^2) by Best-Fitting Functions

	FR 10				FR 75		FR 150	
	Bird				Bird		Bird	
	1	2	3	4	5	6	7	8
Exponent	.51	.66	.80	.55	.58	.62	.46	.49
r^2	.85	.96	.96	.94	.92	.96	.77	.79

also observed this effect (e.g., Barowsky & Mintz, 1978), and it undoubtedly contributes to some of the variability in the present observations.

Finally, Figure 3 presents the data collected in the Ball State University laboratories (log transformations of the median pause from the last five sessions at a ratio size). The equations for the lines of best fit for Rats 8, 9, and 12 are $P = .43R^{.63}$, $P = .43R^{.97}$, and $P = .15R^{.66}$, respectively. In each case these account for over 99% of the variability in pausing. As before, these data are well fit by the power function rule, and response run times are not systematically related to ratio size.

DISCUSSION

Although the variability caused by subject and methodological differences precludes the suggestion of a specific set of values, the observation that the relationship between pre-ratio pausing and various independent variables is well approximated by a power function is strongly supported by these data. Such relationships are well known in biology (e.g., Schmidt-Nielson, 1972), as well as in the operant literature (e.g., Stubbs, Pliskoff, & Reid, 1977), and the present results seem congruent with the conclusion of deVilliers and Herrnstein (1977) that power functions provide the most accurate measurement of response strength with latency-generated data.

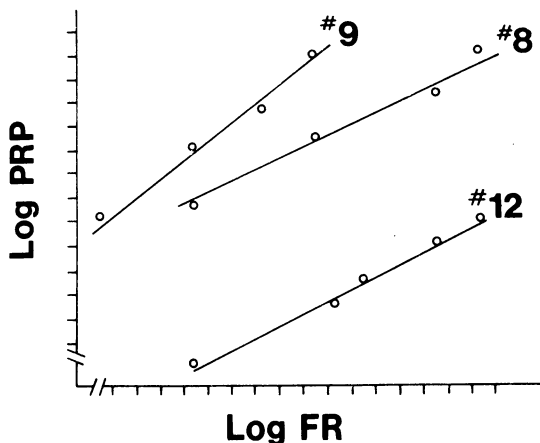


Figure 3. Logarithm of pre-ratio pause as a function of logarithm of ratio size for Rats 8, 9, and 12 from the Ball State University laboratories. Solid lines represent lines of best fit calculated by method of least squares.

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