

AN EQUATION FOR BEHAVIORAL CONTRAST

BEN A. WILLIAMS AND JOHN T. WIXTED

UNIVERSITY OF CALIFORNIA, SAN DIEGO

Pigeons were trained on a three-component multiple schedule in which the rates of reinforcement in the various components were systematically varied. Response rates were described by an equation that posits that the response-strengthening effects of reinforcement are inversely related to the context of reinforcement in which it occurs, and that the context is calculated as the weighted average of the various sources of reinforcement in the situation. The quality of fits was comparable to that found with previous quantitative analyses of concurrent schedules, especially for relative response rates, with over 90% of the variance accounted for in every case. As with previous research, reinforcements in the component that was to follow received greater weights in determining the context than did reinforcements in the preceding component.

Key words: multiple schedules, quantitative analysis, behavioral contrast, inhibition of reinforcement, matching, pigeons

Response rate in a multiple schedule is a function of relative rate of reinforcement, at least to a first approximation (Williams, 1983a). Several theoretical analyses have specified this relationship in quantitative terms, in the hope of more clearly delineating the underlying principles of schedule interactions. One approach is the generalized matching law (Baum, 1974; Lander & Irwin, 1968), as given by Equation 1, in which B_1 represents response rate in component 1, B_2 represents response rate in component 2, R_1 and R_2 the corresponding reinforcement rates, b the bias toward one component or the other, and a the sensitivity of the relative response rates to the distribution of reinforcement:

$$\frac{B_1}{B_2} = b \left(\frac{R_1}{R_2} \right)^a \quad (1)$$

Although Equation 1 has been shown to describe interactions in multiple schedules with considerable accuracy (see Table 1 of Williams, 1983a), it has the limitation of describ-

ing only relative response rates, with no obvious method of extension to absolute rates that presumably are more fundamental. Moreover, McLean and White (1983) have shown that the degree of sensitivity of relative response rates to the reinforcement distribution may be totally independent of contrast interactions between the two components of the multiple schedule. That is, a high value of a may result from a large amount of alternative reinforcement that competes with the operant response within a given component, and thus may occur in the complete absence of behavioral contrast. To the extent that an account of contrast is a major concern, therefore, some alternative formulation seems desirable.

Herrnstein (1970) proposed Equation 2, derived from his description of response rates in concurrent and simple variable-interval (VI) schedules. The terms of Equation 2 correspond to those of Equation 1 with the addition of R_0 corresponding to reinforcement in the situation other than that scheduled by the experimenter, and with k corresponding to the asymptotic response rate. Equation 2 captures the degree of interaction between the components by the parameter m , which is assumed to vary between 0 and 1 as a function of the variables that determine the degree of interaction (typically the duration of the schedule components). The derivation of relative response rates is then given by writing Equation 2 for each separate component as shown in Equation 3:

This research was supported by NIMH research grant 1 R01 MH 35572-02 and NSF grant BNS 84-08878 to the University of California. Portions of this research were reported at the 1982 meeting of the Psychonomics Society. The authors thank M. Davison, E. Fantino, R. J. Herrnstein, and J. A. Nevin for their helpful comments on previous versions of the manuscript.

John T. Wixted is now at Emory University. Requests for reprints should be addressed to Ben A. Williams, Department of Psychology, C-009, University of California at San Diego, La Jolla, California 92093.

$$B_1 = k \frac{R_1}{R_1 + mR_2 + R_o}; \quad (2)$$

$$\frac{B_1}{B_2} = \frac{k_1 \frac{R_1}{R_1 + mR_2 + R_o}}{k_2 \frac{R_2}{R_2 + mR_1 + R_o}}. \quad (3)$$

Although Equations 2 and 3 do have the advantage of specifying the relation between relative and absolute response rates, they also make several incorrect predictions, as noted by several investigators (de Villiers, 1977; McLean & White, 1983; McSweeney, 1980; Speelman & Gollub, 1974). Perhaps the most serious of these is the prediction that absolute response rates during both components will decrease when component duration is shortened, whereas in fact the response rate in the component with the higher reinforcement rate typically increases (Williams, 1980). A related problem is that Equation 2 predicts no contrast after a transition from a simple VI to a multiple VI extinction schedule, and, conversely, predicts that there should be a decrease in response rate when a simple VI is changed to a multiple VI VI with equal rates of reinforcement. The reason for both predictions is that any increase in the denominator of Equation 2 (either by increasing m or by increasing R_2) should decrease the response rate.

McLean and White (1983) also have argued that Equation 2 is conceptually inconsistent with the matching law upon which it was originally based. According to Herrnstein (1970, 1974), the parameter k in Equation 2 refers to the total amount of behavior possible in the situation, and should depend only on the units of measurement. Thus, during Component 1 of a multiple schedule, the only behavior possible is the key pecking under the control of the particular discriminative stimulus plus the other activities that are maintained by the reinforcers not scheduled by the experimenter (R_o). Similarly, during Component 2, the behavior possible is pecking occasioned by the second discriminative stimulus and, again, the alternative activities maintained by R_o . Letting B_o correspond to R_o , therefore, the sum of B_1 and B_o and the sum of B_2 and B_o should both equal k . However, this cannot be true if the value of the reinforcement in the alternative component has an

effect. Thus, to the extent that successive interactions occur, they cannot be explained within the matching framework proposed by Herrnstein (but see Staddon, 1982, and McLean & White, 1983, for alternative formulations based on the matching law).

Equations 1 and 2 both assume that relative rate of reinforcement is a molar variable, which cannot be reduced to more elementary processes. This assumption is challenged by several demonstrations that contrast interactions are temporally asymmetric when multiple schedules with more than two components are investigated (Farley, 1980; Williams, 1976a, 1976b, 1979, 1981). That is, variations in relative rate of reinforcement have produced only weak interactions when variation was due to changes in the preceding schedule, but have produced much larger interactions when the variation was due to changes in the following schedule. Because the two effects appear to be functionally separate, and because both presumably are operative in the typical two-component schedule, the implication is that relative rate of reinforcement in the typical schedule cannot be a unitary variable.

Despite the problem of two effects operating simultaneously, results from other experimental areas offer strong encouragement for retaining relative rate of reinforcement as a fundamental concept. For example, Fantino's (1977) delay-reduction account of choice in concurrent-chains schedules assumes that the conditioned reinforcing properties of a stimulus are a function of its average time to primary reinforcement, relative to the average time to primary reinforcement in the situation as a whole. Similarly, Gibbon's (1981) account of autoshaping assumes that the rate of conditioning produced by a given signal-reinforcer relation is always relative to the inter-reinforcement interval in the situation independent of the signal. The considerable success of such formulations, and their independent development, suggests that "context of reinforcement" is a fundamental concept that must be considered for any conditioning situation.

An alternative conceptualization of context of reinforcement with respect to multiple schedules comes from an extension of Catania's (1973) account of behavior in single-schedule situations, based on his concept of "inhibition of reinforcement" (see also Keller,

1980). Catania argued that reinforcement has two effects: increasing the strength of the response on which it is contingent according to Equation 4, and "inhibiting" all behavior in the situation according to Equation 5. Note that K is in units of responses/reinforcers and C is in units of reinforcers/time, and that ΣR refers to all sources of reinforcement in the situation (and is equal to R_1 when only a single reinforcement schedule is presented):

$$f(E) = KR_1; \quad (4)$$

$$f(I) = \frac{1}{1 + \frac{\Sigma R}{C}}. \quad (5)$$

Combining the two expressions produces the full equation for response rate,

$$B_1 = \frac{KCR_1}{\Sigma R + C},$$

which becomes Equation 6 when the combined parameters KC are set equal to a new constant, s .

$$B_1 = \frac{sR_1}{\Sigma R + C}. \quad (6)$$

Note that this implies that s is in units of responses/time and that its estimation will be directly correlated with estimates of C . Also note that Equation 6 is similar to Herrnstein's (1970) account of behavior in simple schedules, but the interpretation of parameters is different.

Catania's (1973) concept of inhibition by reinforcement can be extended to multiple schedules by assuming that the amount of such inhibition is a function of the average rate of reinforcement in the situation. However, a simple arithmetic average is inappropriate, given that different sources of reinforcement produce different degrees of interaction. Thus, it is necessary to use a weighted average in which different weights are assigned to the different sources of reinforcement. Equation 7 captures this idea, with B_n referring to the response rate in component n , R_n to the reinforcement rate in that component, R_{n-1} to the reinforcement in the preceding component, R_{n+1} to the reinforcement in the following component, p and f to the weights for the preceding and following sources of reinforce-

ment relative to that in the prevailing component (which is always 1.0), and s and C to the same as in Equation 4:

$$B_n = s \frac{R_n}{\frac{R_n + pR_{n-1} + fR_{n+1}}{1 + p + f} + C}. \quad (7)$$

The rationale underlying Equation 7 is that contrast occurs because of changes in the context of reinforcement, which in turn produces varying degrees of response inhibition. Thus, for a given component in which the reinforcement schedule is held constant, the excitatory effects of reinforcement will be constant, but the degree of inhibition will vary as a function of the weighted average of the reinforcement in the situation. Moreover, the context of reinforcement will vary depending upon which component is present at any given time, and the effects of reinforcement variation on the weighted average will depend on the locus of variation. At issue is whether such an approach can provide an accurate description of the interactions that are actually observed. The present study addressed this issue by investigating the effects of parametric variations of reinforcement rate in a three-component multiple schedule.

METHOD

Subjects

Four White Carneaux pigeons were maintained at 80% of their free-feeding weights by additional feeding, when necessary, following experimental sessions. All subjects had extensive experience with multiple schedules in the same apparatus as used here (see Williams, 1981, Experiment 2).

Apparatus

A standard conditioning chamber was constructed from a plastic picnic chest. The chamber was approximately 30.5 cm in all dimensions. On the front panel were mounted two pigeons keys, 1.7 cm in diameter, which required a minimum force of 0.10 N for operation. Only the left key was used, and the right key remained dark throughout the study. The stimuli were projected onto the rear of the key by a standard 28-V, 12-stimulus IEE in-line projector. Ten cm below the keys was a 5- by 5-cm aperture through which the birds

Table 1

Schedules of reinforcement and number of sessions for the various experimental conditions.

Condi- tion	Schedule value (min)			No. of ses- sions
	Comp. A	Comp. B	Comp. C	
1	VI 3	VI 6	VI 1.25	25
2	VI 1.25	VI 6	VI 3	20
3	VI 6	VI 1.25	VI 3	30
4	VI 3	VI 1.25	VI 6	30
5	VI 1.25	VI 3	VI 6	30
6	VI 6	VI 3	VI 1.25	30
7	VI 3	VI 3	VI 3	25
8	VI 6	VI 3	VI 6	25
9	VI 1.25	VI 1.25	VI 6	25
10	VI 1.25	VI 1.25	VI 1.25	20
11	VI 6	VI 6	VI 6	25

could eat when the food hopper was activated. No houselight was used, so the chamber was completely dark except for the illumination provided by the keylight and the occasional presentations of the hopper light.

Procedure

A three-component multiple schedule was used throughout training, with the fixed sequence, ABC ABC, etc. The stimulus that accompanied Component A was three horizontal white lines on a dark background; for Component B, a diffuse green keylight; and for Component C, a white circle on a yellow background. The schedules in effect during each component for each condition are shown in Table 1, along with the number of sessions of training on each. The number of sessions, determined prior to each condition, was based on experience with respect to how much training would be necessary for responding of all four subjects to stabilize. Additional training (in blocks of five sessions) was used on those occasions when the responding in all three components did not appear by visual inspections to be stable. The various schedules were constructed from the distribution described by Fleshler and Hoffman (1962) with 18 different intervals for the VI 1.25- and 3-min schedules and 12 different intervals for the VI 6-min schedule. Component duration was 10 s throughout the experiment because previous work has shown this to be the duration that produces maximal schedule interaction (Shimp & Wheatley, 1971). The component timer stopped during reinforcement (2.5-s access to

Purina pigeon chow). Each session was in effect for 150 cycles, lasting about 75 min.

Data Analysis

The parameters of the various equations were fit using an iterative nonlinear regression program that is part of the University of California statistical package that is commercially available (Ralston, 1981). The stability criterion for the fit was that the error variance not decrease by more than 0.001% over five successive iterations.

RESULTS

Evidence for Asymmetric Interactions

A major premise of the weighted-average model (Equation 7) is that separate terms are required for the component schedule that precedes and the component schedule that follows the component of immediate concern, because those two sources of alternative reinforcement have systematically differing effects on behavior. A previous study with the same subjects (Williams, 1981, Experiment 2) addressed this issue directly, with the result that contrast effects from the schedule that followed were substantially larger than those from the schedule that preceded (although the responding of one subject, R-38, was affected substantially by both alternative sources of reinforcement). However, that study was conducted considerably prior to the present work, so it is important to establish that similar differences occurred with the present procedure before proceeding to the application of Equation 7 to the entire array of results.

Given the set of schedules shown in Table 1, the best method of determining the differential effects of the preceding versus following schedules is to examine those conditions in which the schedule during one component was held constant while those of the surrounding components were interchanged between successive conditions. Response rates in the constant component can then be compared with respect to whether the higher reinforcement rate occurred in the preceding or in the following component. Five pairs of conditions offer this comparison: Conditions 1 versus 2, 3 versus 4, and 5 versus 6, all with Component B as the constant schedule, and Conditions 2 versus 3 and 4 versus 5 with Component C as the constant schedule. For example, with

Conditions 1 versus 2 as the comparison, a higher response rate in Component B during Condition 2 indicates a larger effect of the following schedule because the frequency of reinforcement in the component schedule that followed was lower in Condition 2 than in Condition 1. If reinforcement frequency in the preceding component schedule had the greater effects on behavior in Component B, response rate should be higher in Condition 1.

Figure 1 summarizes the results of the five dyads relevant to the issue of contrast asymmetry by showing the proportion of the total responding in each pair of conditions during the condition in which the constant component was followed by the lower reinforcement rate (e.g., for Conditions 1 and 2, the proportion of total responding in Component B that occurred during Condition 2). Values greater than .5 indicate a greater effect of the schedule that follows; values less than .5 indicate a greater effect of the schedule that precedes. Across the five comparisons, values greater than .5 were obtained in all five cases for Subjects R-75 and R-56, in four of five cases for Subject R-63, and in 3 of 5 cases for Subject R-38. It should be noted that two of the three values below .5 occurred in the first comparison (Component B for Conditions 1 vs. 2), in which the effect of the preceding schedule might be expected to be larger, because a strong local contrast effect at the beginning of a component is more likely early in training (see Williams, 1983a, for a review). In general, therefore, the present data provide strong evidence for asymmetrical schedule interactions. It also should be noted that the differences from .5 that are shown do not reflect the absolute size of the effect of either the preceding or following schedule, but only the differences between those effects. It is thus possible for both effects to be large, but for the difference between them to be small and inconsistent. It is partly for that reason that a quantitative description is desirable that represents each source of alternative reinforcement by a separate term.

Evaluations of Equations that Predict Absolute Rates of Responding

The data shown in Table 2 were fit by Equation 7 with a nonlinear regression procedure. Four separate fits were made for data from each subject: one for response rates in

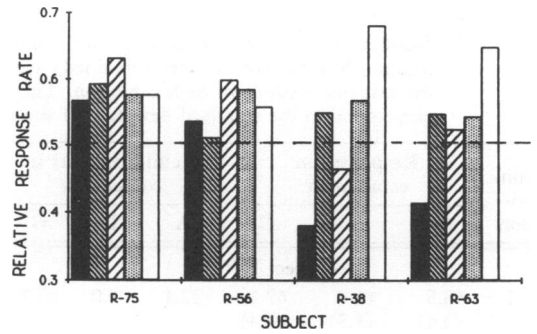


Fig. 1. Relative response rates for the unchanged components for pairs of conditions in which the locations of the surrounding schedules were interchanged. These relative rates were obtained by dividing the number of responses in the condition of each pair in which the following component schedule had the lower reinforcement rate, by the sum of responses during both conditions of the pair. Each bar corresponds to a separate comparison, the order being Condition 1 versus 2 (Component B), 3 versus 4 (B), 5 versus 6 (B), 2 versus 3 (C), and 4 versus 5 (C).

each component, and one for the pooling of response rates from all components. Thus, for fits to individual components there were 11 data points (10 for R-75 because it became ill before completion of the last condition), whereas for the fit to the aggregates there were 33 (30 for R-75).

Table 3 shows the parameter values for each separate fit, along with the percentage of variance accounted for. In general it is clear that the fits for the individual components were better than those for the aggregates. The median percentage of variance accounted for by the fits to the individual components was 91.5 (mean = 88.7), whereas the corresponding percentage for the aggregate fits was 83.1 (mean = 82.9). The apparent reason for this difference was the variance in the s parameter, because there is prior evidence that such variation represents more than experimental error; that is, other research in our laboratory has shown consistent differences in the response rates maintained by different types of stimuli even when correlated with identical reinforcement schedules. Although such differences can be captured by different s values for the fits to individual components, they are averaged out for the fits to the aggregates, and thus contribute to error variance.

The quality of the fits also was variable across subjects. Excellent fits were obtained

Table 2

Results for individual subjects on all conditions. Response rates are in terms of responses/minute. Reinforcement rates (obtained) are in terms of reinforcements/hour. Data are from the last five sessions of each condition. The numbers in parentheses below each response rate correspond to the standard deviation of the rates across the five sessions.

Con- di- tion	Responses in component			Reinforcements in component			Con- di- tion	Responses in component			Reinforcements in component		
	A	B	C	A	B	C		A	B	C	A	B	C
Subject R-75													
1	45.5 (3.4)	16.4 (1.5)	67.1 (2.4)	22.1	9.0	47.7	1	36.6 (3.7)	31.6 (1.9)	88.4 (6.5)	21.2	10.4	51.8
2	70.4 (4.9)	21.4 (2.8)	37.3 (1.1)	46.4	10.4	23.4	2	67.6 (3.2)	19.4 (2.6)	48.4 (1.4)	45.0	10.4	22.1
3	20.7 (3.9)	46.2 (6.4)	50.3 (9.4)	9.9	41.4	23.0	3	29.9 (3.1)	87.2 (7.8)	63.4 (1.3)	10.1	44.2	23.6
4	28.8 (3.6)	66.8 (6.3)	22.8 (4.2)	21.6	47.3	10.4	4	41.4 (2.5)	105.8 (4.6)	33.6 (1.1)	22.5	47.6	12.4
5	54.2 (5.1)	43.0 (8.1)	16.9 (4.1)	46.8	20.7	10.4	5	61.6 (4.4)	46.2 (2.1)	15.9 (3.9)	47.3	23.0	9.5
6	21.6 (2.3)	25.1 (1.8)	52.4 (4.5)	9.5	23.4	47.7	6	23.3 (3.0)	53.3 (6.2)	60.7 (4.5)	11.3	20.7	47.3
7	28.7 (3.2)	34.5 (4.9)	37.0 (5.3)	22.1	22.5	27.9	7	38.0 (1.2)	54.6 (5.9)	44.0 (1.1)	22.5	21.7	25.7
8	20.5 (4.2)	39.1 (6.1)	25.5 (5.1)	9.9	23.4	10.8	8	26.8 (2.9)	53.0 (3.7)	25.6 (2.7)	10.4	21.6	10.4
9	35.7 (5.6)	66.1 (10.2)	15.1 (1.9)	38.7	49.5	11.3	9	55.5 (4.7)	82.6 (6.5)	19.5 (2.4)	40.1	49.5	10.8
10	31.2 (2.9)	43.8 (5.2)	39.1 (4.1)	38.7	51.3	56.7	10	42.6 (4.3)	63.2 (6.3)	44.1 (7.5)	38.7	49.5	58.5
11	—	—	—	—	—	—	11	22.7 (3.6)	32.2 (2.6)	27.3 (2.6)	10.8	10.8	11.3
Subject R-56													
1	49.8 (5.4)	18.2 (1.5)	68.6 (1.4)	22.1	9.9	51.3	1	54.9 (2.9)	27.9 (1.8)	59.8 (4.6)	21.6	9.0	47.3
2	72.9 (3.2)	21.0 (2.9)	49.1 (3.8)	45.9	9.0	23.0	2	54.7 (4.8)	19.6 (3.8)	43.2 (5.7)	46.8	10.8	23.4
3	33.8 (5.2)	70.7 (5.1)	68.8 (5.2)	10.4	41.4	22.5	3	25.8 (2.1)	53.4 (2.4)	51.2 (4.2)	10.9	41.3	22.5
4	51.6 (4.6)	74.2 (1.9)	38.4 (4.9)	22.5	46.8	9.9	4	31.2 (4.8)	64.2 (5.4)	27.6 (3.7)	22.5	39.6	9.5
5	72.4 (1.7)	67.8 (5.6)	30.6 (4.1)	45.5	21.6	9.5	5	46.7 (1.8)	44.1 (5.4)	15.0 (3.7)	46.8	22.1	12.2
6	40.2 (2.0)	45.7 (3.1)	67.4 (3.1)	9.9	22.1	50.0	6	23.9 (2.4)	40.3 (6.0)	46.0 (5.3)	9.9	23.0	47.7
7	62.4 (7.9)	60.8 (4.6)	64.6 (7.4)	21.2	23.0	24.8	7	34.1 (4.6)	44.5 (2.4)	45.7 (2.6)	22.1	23.9	27.0
8	47.2 (6.7)	66.8 (3.5)	52.1 (4.7)	10.8	22.5	10.4	8	36.0 (2.2)	59.0 (2.3)	43.1 (2.6)	11.3	24.3	11.7
9	61.1 (1.8)	70.1 (3.7)	29.8 (3.8)	40.5	45.9	11.7	9	38.8 (3.6)	56.9 (4.2)	21.4 (5.3)	41.9	49.1	10.8
10	54.8 (3.3)	50.7 (12.0)	63.7 (2.6)	41.9	45.9	55.4	10	41.0 (3.7)	50.2 (5.0)	43.4 (4.1)	41.0	49.5	59.9
11	47.9 (2.6)	45.1 (1.6)	53.0 (4.5)	12.6	11.3	11.3	11	32.0 (2.8)	35.6 (3.1)	33.8 (3.6)	10.4	10.4	10.4
Subject R-63													
1	54.9 (2.9)	27.9 (1.8)	59.8 (4.6)	21.6	9.0	47.3	1	54.9 (2.9)	27.9 (1.8)	59.8 (4.6)	21.6	9.0	47.3
2	54.7 (4.8)	19.6 (3.8)	43.2 (5.7)	46.8	10.8	23.4	2	54.7 (4.8)	19.6 (3.8)	43.2 (5.7)	46.8	10.8	23.4
3	25.8 (2.1)	53.4 (2.4)	51.2 (4.2)	10.9	41.3	22.5	3	25.8 (2.1)	53.4 (2.4)	51.2 (4.2)	10.9	41.3	22.5
4	31.2 (4.8)	64.2 (5.4)	27.6 (3.7)	22.5	39.6	9.5	4	31.2 (4.8)	64.2 (5.4)	27.6 (3.7)	22.5	39.6	9.5
5	46.7 (1.8)	44.1 (5.4)	15.0 (3.7)	46.8	22.1	12.2	5	46.7 (1.8)	44.1 (5.4)	15.0 (3.7)	46.8	22.1	12.2
6	23.9 (2.4)	40.3 (6.0)	46.0 (5.3)	9.9	23.0	47.7	6	23.9 (2.4)	40.3 (6.0)	46.0 (5.3)	9.9	23.0	47.7
7	34.1 (4.6)	44.5 (2.4)	45.7 (2.6)	22.1	23.9	27.0	7	34.1 (4.6)	44.5 (2.4)	45.7 (2.6)	22.1	23.9	27.0
8	36.0 (2.2)	59.0 (2.3)	43.1 (2.6)	11.3	24.3	11.7	8	36.0 (2.2)	59.0 (2.3)	43.1 (2.6)	11.3	24.3	11.7
9	38.8 (3.6)	56.9 (4.2)	21.4 (5.3)	41.9	49.1	10.8	9	38.8 (3.6)	56.9 (4.2)	21.4 (5.3)	41.9	49.1	10.8
10	41.0 (3.7)	50.2 (5.0)	43.4 (4.1)	41.0	49.5	59.9	10	41.0 (3.7)	50.2 (5.0)	43.4 (4.1)	41.0	49.5	59.9
11	32.0 (2.8)	35.6 (3.1)	33.8 (3.6)	10.4	10.4	10.4	11	32.0 (2.8)	35.6 (3.1)	33.8 (3.6)	10.4	10.4	10.4

Table 3

Best fitting values for the parameters of Equation 7. Also presented is the percentage of variance accounted for by the best fit. Shown in parentheses below each parameter estimate is its standard deviation. Four fits are presented for each subject: one for each separate component, and one for all components pooled together.

	Component				Component			
	A	B	C	All	A	B	C	All
	R-75				R-56			
<i>s</i>	42.4 (11.0)	66.9 (10.1)	41.4 (11.3)	49.3 (6.6)	65.2 (5.4)	59.7 (7.0)	59.8 (3.7)	61.3 (3.2)
<i>p</i>	0.15 (0.22)	-0.27 (0.14)	0.42 (0.30)	0.05 (0.13)	0.12 (0.06)	0.11 (0.11)	0.03 (0.05)	0.09 (0.04)
<i>f</i>	1.21 (0.35)	1.04 (0.21)	0.51 (0.31)	0.92 (0.19)	0.18 (0.07)	0.51 (0.15)	0.32 (0.07)	0.32 (0.05)
<i>C</i>	3.3 (7.8)	20.7 (7.2)	1.1 (7.2)	7.8 (4.6)	3.3 (2.2)	2.4 (2.8)	1.0 (1.4)	1.8 (1.3)
% Var.	93.1	97.9	84.6	88.5	89.6	92.2	94.8	88.4
	R-38				R-63			
<i>s</i>	74.7 (13.8)	97.4 (21.4)	63.3 (22.8)	76.5 (14.4)	45.5 (5.4)	53.8 (5.7)	45.1 (6.9)	47.7 (3.7)
<i>p</i>	0.29 (0.15)	0.93 (0.59)	0.28 (0.41)	0.42 (0.24)	-0.07 (0.08)	0.24 (0.12)	0.04 (0.14)	0.06 (0.07)
<i>f</i>	0.17 (0.15)	0.46 (0.41)	0.46 (0.51)	0.45 (0.24)	0.44 (0.14)	0.28 (0.11)	0.35 (0.18)	0.37 (0.09)
<i>C</i>	18.1 (8.3)	19.7 (10.1)	8.9 (11.8)	14.1 (7.5)	3.1 (3.1)	4.2 (2.9)	1.7 (3.5)	2.7 (1.9)
% Var.	93.0	92.9	74.0	77.0	83.7	90.9	77.7	77.8

for Subjects R-75 and R-56, with the percentage of variance accounted for generally over 90%. For Subjects R-38 and R-63, there were good fits to some individual components, but in general the fits were considerably poorer.

Of major interest are the values of the various parameters. The *s* and *C* parameters are similar to those reported in the literature when Equation 6 was fit to response rates maintained by single VI schedules (de Villiers & Herrnstein, 1976), although it should be noted that the value of *s* does not correspond to the maximum response rate possible (the asymptote instead is $s[1 + p + f]$). Of greatest interest are the *p* and *f* values. For the 16 different fits shown in Table 3, 14 have a larger value for *f* than for *p*, and in most cases the difference is substantial. In terms of their absolute values, 14 of the 16 values of *p* are positive, with a mean of 0.18, and all 16 values of *f* were positive with a mean of 0.50. The fits are thus consistent with previous findings (and Figure 1) showing that schedule

interactions are due predominantly to variations in reinforcement rate in the component schedule that follows. However, the consistently positive values of *p* also indicate some contribution from the component schedule that precedes. The magnitude of this contribution varied substantially across subjects, as only R-38 showed a strong effect. Previous data from the same 4 subjects showed a similar pattern (see Experiment 2 of Williams, 1981), suggesting that such individual differences persist over substantial periods of time.

Fits of Relative Response Rates

A major potential source of variability with respect to absolute rates of responding was condition-to-condition variation in asymptotic response rates. Such variation should not be surprising, given the long duration of the experiment (over 1 year), inasmuch as "organismic" variables might change substantially over that length of time. This source of variability can be reduced by using relative rates of responding, on the assumption that organ-

ismic variables affect responding in each component equally. To do this, Equation 8 was derived by dividing Equation 7 with respect to B_n by the same equation with respect to B_{n+1} (note that for R_{n+1} , the component schedule that followed was component $n - 1$, because the three-component schedule recycled continuously):

$$\frac{B_n}{B_{n+1}} = \frac{s_n \frac{R_n}{R_n + pR_{n-1} + fR_{n+1}} + C}{s_{n+1} \frac{R_{n+1}}{R_{n+1} + pR_n + fR_{n-1}} + C}.$$

Rearranging terms:

$$\frac{B_n}{B_{n+1}} = \frac{s_n}{s_{n+1}} \cdot \frac{R_n}{R_{n+1}} \cdot \frac{R_{n+1} + pR_n + fR_{n-1} + C + pC + fC}{R_n + pR_{n-1} + fR_{n+1} + C + pC + fC},$$

and setting $\frac{s_n}{s_{n+1}} = s'$ and $C(1 + p + f) = C'$:

$$\frac{B_n}{B_{n+1}} = s' \frac{R_n}{R_{n+1}} \cdot \frac{R_{n+1} + pR_n + fR_{n-1} + C'}{R_n + pR_{n-1} + fR_{n+1} + C'} \quad (8)$$

The data shown in Table 2 were fit by Equation 8, once again using an iterative non-linear regression program. An initial difficulty in determining the best fitting parameter values was that the values of p , f , and C tended to be inversely correlated, so that large values of C (not C') occasionally occurred in conjunction with small values of p or f (or vice versa). To avoid this problem, the value of C (not C') was set constant at the value derived from the fit of the aggregate of the absolute rates shown in Table 3 (e.g., for Subject R-75, C was set constant at 7.8). This added a degree of freedom to the curve-fitting procedure and also produced p and f values that were interpretable, with the results shown in the first column for each subject in Table 4.

The pattern of parameter values obtained with the fit of Equation 8 was similar to that for Equation 7 (see Table 3) except that the weights for p and f tended to be slightly larger. Of the 16 separate fits of Equation 8, 15 estimates of p were positive, and all 16 estimates of f were positive. The mean value of p was

0.24, and that of f was 0.58. The major difference between fits of Equations 7 and 8 was that Equation 8 accounted for substantially more of the variance, despite having one fewer free parameter. Considering only the fits to the individual pairs of components (e.g., A/B), the median percentage of variance accounted for was 96.5 (mean = 95.5) and in only one case was it less than 90%. The fits of the aggregates of all pairs of components were substantially worse, but this was expected because of the considerable variability in s' with respect to the individual pairs of components; that is, s' for the fits to the aggregates was essentially the mean of the s' values for the individual component pairs, so that any variation around that mean increased the error variance.

Although the estimates of both p and f were consistently positive, it remains to be determined whether the inclusion of both alternative sources of reinforcement contributed significantly to the functionally effective context of reinforcement. In other words, would the fits of the data be significantly worse if one or the other source of alternative reinforcement were omitted from the equation? To make this assessment, two additional equations were fit to the data. Equation 9 is analogous to Equation 7 except that the term for the component schedule that precedes has been omitted; Equation 10 is similar except for omission of the term for the component schedule that follows. Thus,

$$B_n = s \frac{R_n}{\frac{R_n + fR_{n+1}}{1 + f} + C} \quad (9)$$

and

$$B_n = s \frac{R_n}{\frac{R_n + pR_{n-1}}{1 + p} + C} \quad (10)$$

The corresponding expressions for relative response rates are then derived by writing Equations 9 and 10 for both components n and $n + 1$, with Equations 11 and 12 as the result (where $C' = C[1 + f]$ for Equation 11 and $C[1 + p]$ for Equation 12):

$$\frac{B_n}{B_{n+1}} = s' \frac{R_n}{R_{n+1}} \cdot \frac{R_{n+1} + fR_{n-1} + C'}{R_n + fR_{n+1} + C'} \quad (11)$$

and

$$\frac{B_n}{B_{n+1}} = s' \frac{R_n}{R_{n+1}} \cdot \frac{R_{n+1} + pR_n + C'}{R_n + pR_{n-1} + C'}. \quad (12)$$

The fits provided by Equations 11 and 12 are shown in the second and third columns under each subject's listings in Table 4. In general, the quality of the fits was substantially worse than that provided by Equation 8, which included both alternative sources of reinforcement. When the term for the component schedule that precedes was removed (Equation 11), the mean percentage of variance accounted for dropped from 95.5 to 88.0, although this difference occurred primarily because of only 2 subjects, R-38 and R-63. With removal of the term for the component schedule that follows (Equation 12), the drop in variance accounted for was considerably greater, from 95.5 to 67.9%. Once again Subject R-38 was notably different from the other 3 subjects, as the change in quality of the fit to its data was approximately equal when either the preceding or following component schedule was removed. For the remaining 3 subjects, the term for the following component schedule was more important, as the reduction in the percentage of variance accounted for was substantially greater when its corresponding term was removed.

Because Equation 8 has one more free parameter than Equations 11 or 12, and the addition of any free parameter will always increase the variance accounted for, it is important to establish that the better fits provided by Equation 8 represent more than simply the absorption of error variance. The difference in variance accounted for by Equation 8, versus either Equation 11 or Equation 12, was thus tested statistically by an F test as given by Equation 13 (Cohen & Cohen, 1975, pp. 135–136) in which R_1^2 refers to the proportion of variance accounted for by Equation 8, R_2^2 to the proportion of variance accounted for by the alternative equation (either Equation 11 or 12), k_1 to the number of independent parameters associated with Equation 8, k_2 to the number of independent parameters associated with the alternative equation, and N to the number of observations being fitted. The degrees of freedom corresponding to the numerator and denominator of the F ratio is then given by $k_1 - k_2$ and $N - k_1 - 1$, respectively. Thus,

$$F = \frac{(R_1^2 - R_2^2)/(k_1 - k_2)}{(1 - R_1^2)/(N - k_1 - 1)}. \quad (13)$$

The resulting F values are shown in Table 5, with those significant at the .05 level of confidence indicated by asterisks. All but one of the comparisons with the following component schedule excluded were reliable, whereas 10 of the 16 comparisons with the preceding component schedule excluded were significant. All of the differences involving fits to the aggregate data (that had greater power because of the larger number of degrees of freedom) were reliable, which implies that both the preceding and the following schedule components provided significant increments to the quality of the description of the relative response rates, and thus contributed independently to the context of reinforcement.

DISCUSSION

Relativistic Effects of Reinforcement

The central issue addressed here is whether interactions in multiple schedules can be characterized adequately by a relativistic conception of reinforcement that regards the response-strengthening effect of any absolute rate of reinforcement to be inversely related to the "context" in which it occurs. A critical assumption in testing this conception was that the context can be conceptualized as the weighted average of the various sources of reinforcement available in the situation—in the present case, the prevailing component of the multiple schedule, the component that just preceded, and the component that consistently follows. As noted in the introduction, the use of different weights seems to be demanded by previous research showing that the component schedule that consistently follows is a more potent source of behavioral contrast than is the component schedule that precedes (Williams, 1981). The present analysis is consistent with those previous findings: For 3 of the 4 subjects, the empirically determined weights for the following component schedule were considerably larger than those for the preceding component schedule. For the remaining subject, the contributions of the two alternative sources of reinforcement were comparable.

The validity of the weighted-average con-

Table 4

Best fitting values for the parameters of Equations 8, 11, and 12. Also presented is the percentage of variance accounted for by the best fit. Shown in parentheses below each parameter estimate is its standard deviation. Four fits are presented for each subject, with the relevant response ratios indicated under the component column.

		Eq. 8	Eq. 11	Eq. 12	Eq. 8	Eq. 11	Eq. 12
		R-75			R-56		
Comp. A/B	s'	0.91 (0.07)	0.99 (0.12)	1.15 (0.23)	1.07 (0.06)	1.11 (0.13)	1.19 (0.22)
	p	0.27 (0.09)		0.31 (0.25)	0.21 (0.05)		0.34 (0.21)
	f	0.94 (0.25)	0.69 (0.24)		0.63 (0.10)	0.54 (0.15)	
	% Var.	97.5	91.8	65.1	97.4	85.8	54.0
Comp. B/C	s'	0.91 (0.11)	0.91 (0.13)	1.25 (0.32)	0.91 (0.05)	1.02 (0.05)	1.09 (0.11)
	p	0.17 (0.13)		0.36 (0.33)	0.09 (0.03)		0.26 (0.16)
	f	1.32 (0.47)	1.34 (0.48)		0.44 (0.06)	0.45 (0.07)	
	% Var.	96.2	94.8	65.8	97.6	95.0	59.0
Comp. C/A	s'	1.04 (0.05)	1.04 (0.05)	1.20 (0.13)	1.02 (0.05)	1.02 (0.05)	1.09 (0.11)
	p	0.03 (0.03)		0.13 (0.09)	0.03 (0.03)		0.12 (0.07)
	f	0.39 (0.08)	0.40 (0.07)		0.28 (0.06)	0.30 (0.06)	
	% Var.	97.6	97.4	77.1	93.2	92.1	56.2
ALL	s'	0.96 (0.07)	0.99 (0.07)	1.21 (0.13)	1.00 (0.05)	1.02 (0.06)	1.11 (0.10)
	p	0.14 (0.06)		0.26 (0.12)	0.09 (0.04)		0.23 (0.08)
	f	0.82 (0.17)	0.78 (0.17)		0.43 (0.07)	0.44 (0.07)	
	% Var.	92.7	90.6	65.6	87.7	84.2	50.4
		R-38			R-63		
Comp. A/B	s'	0.71 (0.07)	0.91 (0.19)	0.81 (0.10)	0.86 (0.06)	0.94 (0.13)	0.94 (0.15)
	p	1.45 (0.56)		0.96 (0.42)	0.38 (0.09)		0.43 (0.22)
	f	1.08 (0.57)	0.44 (0.40)		0.59 (0.13)	0.41 (0.16)	
	% Var.	96.9	65.9	90.7	96.0	73.2	65.5
Comp. B/C	s'	1.24 (0.09)	1.31 (0.11)	1.42 (0.17)	1.12 (0.11)	1.12 (0.11)	1.25 (0.22)
	p	0.18 (0.09)		0.28 (0.18)	-0.05 (0.06)		0.20 (0.16)
	f	0.45 (0.13)	0.44 (0.13)		0.48 (0.12)	0.45 (0.12)	
	% Var.	96.7	94.1	85.8	89.7	88.9	48.8
Comp. C/A	s'	1.09 (0.10)	1.18 (0.12)	1.14 (0.09)	1.04 (0.04)	1.04 (0.04)	1.11 (0.11)
	p	0.26 (0.11)		0.27 (0.16)	0.01 (0.03)		0.12 (0.07)

Table 4 (Continued)

	Eq. 8	Eq. 11	Eq. 12	Eq. 8	Eq. 11	Eq. 12
	R-38			R-63		
<i>f</i>	0.14 (0.14)	0.19 (0.15)		0.31 (0.05)	0.32 (0.05)	
% Var.	91.8	82.3	90.4	95.1	95.0	56.9
ALL <i>s'</i>	1.00 (0.07)	1.11 (0.09)	1.14 (0.09)	1.02 (0.06)	1.03 (0.06)	1.11 (0.10)
<i>p</i>	0.43 (0.13)		0.43 (0.13)	0.09 (0.04)		0.23 (0.08)
<i>f</i>	0.53 (0.19)	0.46 (0.16)		0.41 (0.08)	0.42 (0.07)	
% Var.	89.5	79.3	82.6	84.5	82.1	52.8

ception of context of reinforcement can be assessed only indirectly by the present data, by examining how well the data are described by equations derived from that concept. In general, the quality of the description was high, especially for relative response rates, with over 95% of the variance accounted for. Thus, in terms of the criterion of goodness of fit, the relativistic conception of reinforcement was strongly supported. Moreover, all of the parameters of the equations are theoretically meaningful, and the ranges of all values that were derived for those parameters were consistent with the corresponding conceptual interpretations.

An important implication of the present weighted-average conception of context of reinforcement is that it argues strongly against viewing the matching of relative response rates to relative reinforcement rates as the limiting form of multiple-schedule interactions. Thus it suggests a basic difference between multiple and concurrent schedules. Some previous research provides evidence that matching does

occur in multiple schedules with short component durations (Merigan, Miller, & Golub, 1975; Shimp & Wheatley, 1971; Todorov, 1972; Williams, 1983b), but other research challenges the generality of those findings (Charman & Davison, 1982). All such previous research has used two-component multiple schedules, which are incapable of revealing any asymmetry in the effects of components that precede and components that follow (inasmuch as they are always the same component). The fact that the two effects are functionally different causes serious difficulty for any conception of matching as a general law of schedule interactions, because such asymmetry implies that matching cannot occur generally with multiple schedules with three or more components. That is, matching implies that relative response rate produced by a particular relative reinforcement rate should be invariant, whereas the asymmetrical interactions imply that the effect of any given relative reinforcement rate will depend critically upon its location in the sequence of

Table 5

F values for the statistical test given by Equation 13. *F* values which exceeded the .05 level of confidence are indicated by asterisks.

Subject	Eq. 8 vs. Eq. 11				Eq. 8 vs. Eq. 12			
	Component			All	Component			All
	A/B	B/C	C/A		A/B	B/C	C/A	
R-75	13.68*	2.21	0.50	7.48*	77.76*	48.0*	51.25*	96.52*
R-56	31.23*	7.58*	1.13	8.25*	116.86*	112.58*	38.09*	87.94*
R-38	70.0*	5.52	8.11*	28.17*	14.00*	23.12*	1.20	19.06*
R-63	39.90*	0.54	0.14	4.49*	53.58*	27.8*	54.57*	59.31*

components. The same limitation also applies to any use of relative rate of reinforcement as a molar variable that does not include a functional separation of the different sources of reinforcement context (e.g., the generalized matching law: Equation 1).

Extensions to Two-Component Schedules

An important question regarding the generality of the weighted-average context model is how well it can be applied to previous studies of multiple schedule that have used only two components. With such schedules, the components that precede and those that follow are always identical, so the two effects can no longer be considered separately. This combination can be captured by allowing $p + f = m$, so that the corresponding equations for absolute and relative response rates in two-component schedules become Equations 14 and 15, respectively:

$$B_n = s \frac{R_n}{\frac{R_n + mR_{n+1}}{1 + m} + C} \quad (14)$$

and

$$\frac{B_n}{B_{n+1}} = s' \frac{R_n}{R_{n+1}} \cdot \frac{R_{n+1} + mR_n + C'}{R_n + mR_{n+1} + C'} \quad (15)$$

Equation 15 was fit to the data of the three previous studies of two-component multiple schedule that involved short component durations and that varied relative rate of reinforcement over several values. The results are shown in Table 6 along with fits by Equation 1 for comparison. Both equations were fit with the same nonlinear regression procedure as that used with the present results. As occurred in the analysis of the relative response rates described in the Results section, the fit of Equation 12 was complicated by the correlation between the value of m and C , such that these occasionally assumed absolute values that were so high as to be uninterpretable. Consequently, the value of C (not C') was constrained between the values of 0 to 20 reinforcers per hour.

For the experiment by Shimp and Wheatley (1971), the data analyzed were all of the conditions involving component durations of either 2, 5, or 10 s. For the study by Charman and Davison (1982), the data analyzed were taken only from their Experiment 2, which

held component duration constant at 5 s. Shown separately for that study are their conditions in which the two components of the schedule were presented on the same or different keys. Separate conditions involving one versus two response keys were also studied by Merigan et al. (1975), but only the two-key conditions are presented here because those authors reported very weak interactions when only a single key was involved. It should be noted that Merigan et al. varied relative duration of reinforcement, but the other two studies varied relative rate of reinforcement.

Of primary interest from Table 6 is the relative quality of the descriptions provided by the two equations. They appear comparable for the study by Shimp and Wheatley (1971), as both account for more than 90% of the variance for all subjects. They are also comparable for both conditions of the study by Charman and Davison (1982), although both accounted for substantially less of the variance. It also should be noted that the degree of schedule interaction (captured by m and a) was also substantially less in that study. The two equations do differ, however, with respect to the fits of the data of Merigan et al., in which the generalized matching law (Equation 1) provided a more accurate description for all subjects. In general, therefore, Equation 15 provides an excellent description of the results from previous two-component multiple schedules (at least those with brief component durations), although the generalized matching law provides a more accurate description under some circumstances. As noted in the introduction, however, the generalized matching law provides no account of changes in absolute response rates and has no method of depicting the asymmetric effects of the component schedules that precede and that follow the one under consideration when more than two-component schedules are employed.

Problems with the Context Model

Despite the accuracy of description provided by the present model, several features of the analysis presented in the Results section offer reservations about its conceptual adequacy. As shown in Tables 3 and 4, there was considerable variability in the obtained values of the three parameters, particularly for p and f . Such variability implies that the size of the contrast effects depended upon characteristics

Table 6

Best fitting parameter values for Equations 15 and 1 when fit to previous studies using two-component multiple schedules. The number of data points fit for each subject is shown in parentheses next to the study citations.

	Subject	Equation 15				Equation 1		
		s'	m	C	% var.	b	a	% var.
Shimp & Wheatley (9)	13	0.91	0.78	0	91.0	0.87	.80	94.5
	15	1.00	1.04	0	92.9	1.07	.94	97.8
	20	1.05	1.08	0	96.3	1.16	.91	95.1
Charman & Davison (one-key) (5)	151	0.57	1.32	0	80.4	1.07	.61	81.4
	152	0.97	0.15	20	83.1	0.95	.48	91.7
	153	0.94	0.49	0	94.6	0.95	.49	92.8
	154	1.10	0.19	20	54.1	1.07	.44	69.3
	155	0.96	0.25	0	90.6	0.98	.29	81.9
	156	0.90	-0.11	20	88.7	0.91	.27	81.2
Charman & Davison (two-key) (5)	151	1.57	0.40	20	98.1	1.35	.90	87.6
	152	0.44	0.47	0	89.2	0.43	.59	93.7
	153	1.25	0.31	0	64.0	1.15	.48	74.3
	154	0.91	0.14	20	92.0	0.87	.36	86.8
	155	1.59	0.25	0	83.0	1.55	.37	89.2
	156	1.75	0.11	20	95.9	1.78	.39	92.3
Merigan et al. (6)	1	0.94	0.26	0	85.1	0.92	.35	93.2
	2	0.98	0.96	0	77.6	0.95	.88	94.5
	3	1.11	0.76	0	93.0	1.09	.81	97.9
	4	0.99	0.80	0	91.8	0.96	.84	96.2

of the particular stimuli that accompanied a schedule, which seems somewhat implausible. One possible explanation for such effects is that the pairs of components differed with respect to the degree of stimulus similarity, which has been shown to affect the degree of contrast in previous studies (Blough, 1983; White, Pipe, & McLean, 1984).

A more troublesome feature of the parameter estimates was the large variation in the values of C across the various components, and the large degree of error associated with those estimates (see the standard deviations of C in Table 3). Moreover, fits of the relative response rates when C was allowed to vary freely often produced uninterpretable results. A similar problem occurred in the analysis of previous two-component studies (see Table 6); because it was necessary to constrain the values allowed for C , and the estimates of C that were produced ended up at one or the other extreme of the constraint boundaries. In fact, for the majority of subjects C assumed a value of zero, which implies that it contributed nothing to the model's fitting of the data. And because positive values of C represent an essential feature of the model's derivation (see Catania, 1973), the implication is that the

conceptual rationale of the model may be ill-founded. However, the problem with the estimates of C did not occur when Equation 7 was used to describe absolute response rates, as the estimated values of C were all positive and similar to those obtained from fits to data from single VI schedules (de Villiers & Herrnstein, 1976). This suggests that the difficulties associated with the estimates based on fits of relative response rates may have more to do with the method of analysis than with the conceptual basis of the model per se. A possible reason is that in the original derivation of the model (see the introduction), the parameters s and C are correlated, and a similar but inverse correlation should also occur between C and m , given any error in measurement, because they are combined into the parameter C' when Equation 15 is fit to relative response rates. That is, the curve-fitting program produced an estimate of C' , and the value of C was determined algebraically by substituting in the values of m . Any error in the estimate of m would then produce an opposite corresponding error in the value of C , which could be nonsensical in terms of the model.

The role of measurement error also has im-

plications for the criticism of the context model offered by Charman and Davison (1983). They demonstrated that increasing food deprivation decreased the degree of interaction in a multiple schedule, as indexed by the value of a in Equation 1. They then argued that Equation 5 could not account for this change because neither the value of C nor m changed systematically as a function of body weight. Moreover, the estimated values of m from their data typically were substantially greater than 1.0 and the values of C were typically negative. Their method of obtaining these estimates was by an algebraic solution for m and C using Equation 15 for two separate reinforcement ratios for each body weight. Unfortunately, such an algebraic solution assumes no error in measurement. When such errors do occur, as they inevitably do, large systematic distortions in the estimates of the parameters may occur.

To demonstrate the role of measurement error, we used the obtained reinforcement ratios from the data of Charman and Davison (1983) to generate idealized response ratios from Equation 15. For purposes of this simulation, m was assumed to be 0.5 and C was 7.0 (reinforcers/hour). By definition, therefore, the context model fit the data perfectly. These idealized response ratios were then systematically distorted by introducing a 10% bias toward one of the two components of the multiple schedule (i.e., all relative response ratios were multiplied by 1.10). These distorted response ratios were then substituted back into Equation 15 and the values of m and C were determined algebraically by the same method used by Charman and Davison. The result was a pattern quite close to that reported by those authors: m values were typically greater than 1.0 and C values were negative. Given that the original error-free data were generated by the model, the implication is that the parameter estimates provided by the algebraic solutions cannot be taken as serious evidence against the model. Whether a similar argument can be used to account for the inconsistencies in the parameter estimates noted above (particularly with respect to C in Table 6) remains to be determined.

Comparisons with Alternative Models

Whatever problems remain to be resolved with respect to the weighted-context model, a

major argument in its favor is that it is the *only* quantitative description yet proposed that appears capable of handling the major qualitative features of behavioral interactions observed in multiple schedules. As noted in the introduction, the generalized matching law provides no basis for accounting for changes in absolute response rates, including the most salient feature of those changes—behavioral contrast. Similarly, Herrnstein's (1970) extension of his treatment of concurrent schedules to multiple schedules is also deficient for reasons cited in the introduction. The only remaining account that has been advanced is that based on the notion of behavioral competition, first proposed independently by Henton and Iversen (1978) and by Hinson and Staddon (1978) and developed quantitatively by McLean and White (1983) and by Staddon (1982). Accordingly, response rate in one component of a multiple schedule is not directly affected by the reinforcement rate in the alternative component. Instead, changes in response rate are due to variation in the degree of competing behavior *within* that particular component. Changes in response rate that ostensibly occur because of changes in alternative reinforcement are then assumed to be due to the re-allocation of the competing behavior patterns between components.

Although the behavioral-competition approach offers an attractive alternative to the present account based on "context of reinforcement" as a primitive variable, it faces several major difficulties. Not only does it provide no account of the asymmetrical interactions seen in the present study, but its account of contrast in any conventional multiple schedule is based on hypothetical changes in unobserved competing behavior that supposedly mediates the observed changes in response rate. It thus seems unlikely that any quantitative description of the observed behavior will be possible based only on the independent variables manipulated by the experimenter. But perhaps most importantly, behavioral-competition models cannot account for the major finding concerning multiple-schedule interactions—that contrast does not depend upon the behavior maintained in the alternative component but, instead, depends only on the alternative rate of reinforcement (see Williams, 1983, for a more extensive treatment of this problem). In contrast, the

present account provides a quantitative description of both absolute and relative response rates, based entirely on observed independent variables and tied to a major conceptual rationale about response strength (cf. Catania, 1973; Keller, 1980). The accuracy of that description and its ability to incorporate the asymmetrical effects of difference sources of reinforcement context argue strongly in its favor.

REFERENCES

- Baum, W. M. (1974). On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*, **22**, 231-242.
- Blough, P. M. (1983). Local contrast in multiple schedules: The effect of stimulus discriminability. *Journal of the Experimental Analysis of Behavior*, **39**, 427-435.
- Catania, A. C. (1973). Self-inhibiting effects of reinforcement. *Journal of the Experimental Analysis of Behavior*, **19**, 517-526.
- Charman, L., & Davison, M. (1982). On the effects of component durations and component reinforcement rates in multiple schedules. *Journal of the Experimental Analysis of Behavior*, **37**, 417-439.
- Charman, L., & Davison, M. (1983). On the effects of food deprivation and component reinforcer rates on multiple-schedule performance. *Journal of the Experimental Analysis of Behavior*, **40**, 239-251.
- Cohen, J., & Cohen, P. (1975). *Applied multiple regression/correlation analysis for the behavioral sciences*. Hillsdale, NJ: Erlbaum.
- de Villiers, P. A. (1977). Choice in concurrent schedules and a quantitative formulation of the law of effect. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 233-287). Englewood Cliffs, NJ: Prentice-Hall.
- de Villiers, P. A., & Herrnstein, R. J. (1976). Toward a law of response strength. *Psychological Bulletin*, **83**, 1131-1153.
- Fantino, E. (1977). Conditioned reinforcement: Choice and information. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 313-339). Englewood Cliffs, NJ: Prentice-Hall.
- Farley, J. (1980). Automaintenance, contrast, and contingencies: Effects of local vs. overall and prior vs. impending reinforcement context. *Learning and Motivation*, **11**, 19-48.
- Fleshler, M., & Hoffman, H. S. (1962). A progression for generating variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, **5**, 529-530.
- Gibbon, J. (1981). The contingency problem in auto-shaping. In C. M. Locurto, H. S. Terrace, & J. Gibbon (Eds.), *Autoshaping and conditioning theory* (pp. 285-308). New York: Academic Press.
- Henton, W. W., & Iversen, I. H. (1978). *Classical conditioning and operant conditioning: A response pattern analysis*. New York: Springer-Verlag.
- Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior*, **13**, 243-266.
- Herrnstein, R. J. (1974). Formal properties of the matching law. *Journal of the Experimental Analysis of Behavior*, **21**, 159-164.
- Hinson, J. M., & Staddon, J. E. R. (1978). Behavioral competition: A mechanism for schedule interactions. *Science*, **202**, 432-434.
- Keller, K. J. (1980). Inhibitory effects of reinforcement and a model of fixed-interval performances. *Animal Learning & Behavior*, **8**, 102-109.
- Lander, D. G., & Irwin, R. J. (1968). Multiple schedules: Effects of the distribution of reinforcements between components on the distribution of responses between components. *Journal of the Experimental Analysis of Behavior*, **11**, 517-524.
- McLean, A. P., & White, K. G. (1983). Temporal constraint on choice: Sensitivity and bias in multiple schedules. *Journal of the Experimental Analysis of Behavior*, **39**, 405-426.
- McSweeney, F. K. (1980). Differences between rates of responding emitted during simple and multiple schedules. *Animal Learning & Behavior*, **8**, 392-400.
- Merigan, W. H., Miller, J. S., & Gollub, L. R. (1975). Short-component multiple schedules: Effects of relative reinforcement duration. *Journal of the Experimental Analysis of Behavior*, **24**, 183-189.
- Ralston, M. (1981). PAR derivative-free nonlinear regression. In W. J. Dixon (Ed.), *BMDP statistical software* (pp. 305-314). Los Angeles: University of California Press.
- Shimp, C. P., & Wheatley, K. L. (1971). Matching to relative reinforcement frequency in multiple schedules with a short component duration. *Journal of the Experimental Analysis of Behavior*, **15**, 205-210.
- Spealman, R. D., & Gollub, L. R. (1974). Behavioral interactions in multiple variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, **22**, 471-481.
- Staddon, J. E. R. (1982). Behavioral competition, contrast, and matching. In M. L. Commons, R. J. Herrnstein, & H. Rachlin (Eds.), *Quantitative analyses of behavior: Vol. 2. Matching and maximizing accounts* (pp. 243-261). Cambridge, MA: Ballinger.
- Todorov, J. C. (1972). Component duration and relative response rates in multiple schedules. *Journal of the Experimental Analysis of Behavior*, **17**, 45-79.
- White, K. G., Pipe, M.-E., & McLean, A. P. (1984). Stimulus and reinforcer relativity in multiple schedules: Local and dimensional effects on sensitivity to reinforcement. *Journal of the Experimental Analysis of Behavior*, **41**, 69-81.
- Williams, B. A. (1976a). Behavioral contrast as a function of the temporal location of reinforcement. *Journal of the Experimental Analysis of Behavior*, **26**, 57-64.
- Williams, B. A. (1976b). Elicited responding to signals for reinforcement: The effects of overall versus local changes in reinforcement probability. *Journal of the Experimental Analysis of Behavior*, **26**, 213-220.
- Williams, B. A. (1979). Contrast, component duration, and the following schedule of reinforcement. *Journal of Experimental Psychology: Animal Behavior Processes*, **5**, 379-396.
- Williams, B. A. (1980). Contrast, signaled reinforcement, and the relative law of effect. *American Journal of Psychology*, **93**, 617-629.
- Williams, B. A. (1981). The following schedule of reinforcement as a fundamental determinant of steady

- state contrast in multiple schedules. *Journal of the Experimental Analysis of Behavior*, **35**, 293-310.
- Williams, B. A. (1983a). Another look at contrast in multiple schedules. *Journal of the Experimental Analysis of Behavior*, **39**, 345-384.
- Williams, B. A. (1983b). Overmatching in multiple schedules. *Behaviour Analysis Letters*, **3**, 171-182.

Received September 1, 1984
Final acceptance October 13, 1985