CHOICE BETWEEN RESPONSE UNITS: THE RATE CONSTANCY MODEL

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In a conjoint schedule, reinforcement is available simultaneously on two or more schedules for the same response. The present experiments provided food for key pecking on both a random-interval and a differential-reinforcement-of-low-rate (DRL) schedule. Experiment 1 involved ordinary DRL schedules; Experiment 2 added an external stimulus to indicate when the required interresponse time had elapsed. In both experiments, the potential reinforcer frequency from each component was varied by means of a second-order fixed-ratio schedule, and the DRL time parameter was changed as well. Response rates were described by a model stating that time allocation to each component matches the relative frequency of reinforcement for that component. When spending time in a given component, the subject is assumed to respond at the rate characteristic of baseline performance. This model appeared preferable to the absolute-rate version of the matching law. The model was shown to be applicable to multiple-response concurrent schedules as well as to conjoint schedules, and it described some of the necessary conditions for response matching, undermatching, and bias. In addition, the pigeons did not optimize reinforcer frequency.

Key words: conjoint schedules, concurrent schedules, matching law, DRL schedules, random-interval schedules, clock stimulus, key peck, pigeons

Concurrent schedules involve two or more component schedules, and the subject is free to choose between them on each response. In their most commonly studied form (here referred to as *multiple-response schedules*), each component yields the same reinforcer, and each is correlated with a distinctive stimulus. The arrangement involves mutually exclusive routes to the same outcome, with each alternative defined by an external stimulus (e.g., key location). Response and time allocation among the alternatives can be described by the matching law for choice, where the proportion of responses (or time) devoted to an alternative is a function of the proportion of reinforcers derived from that option (Baum, 1979; de Villiers, 1977; Herrnstein, 1970).

Explicit stimulus control and mutual exclu-

siveness are not inherent in concurrent schedules. Instead, the same response can be relevant to two or more schedules simultaneously. This form of concurrent schedules (referred to now as *conjoint schedules*) may not so obviously involve choice. A multiple-response schedule having two variable-interval components will show behavior conforming to the choice matching law; a conjoint schedule with the same components would not provide direct evidence for choice, because the schedule controlling each response is not readily identified. Such schedules lead to consideration of overall response rate rather than choice, and therefore the absolute-rate version of the matching law (de Villiers, 1977; Herrnstein, 1970) seems more applicable than the choice version. The absolute-rate matching law has response rate determined by reinforcer frequency for the reference response relative to the overall reinforcer frequency available from all sources. Given that multiple-response schedules may best be described as involving choice and that conjoint schedules lend themselves to analyses of overall response rate, the two forms of concurrent schedules are difficult to integrate theoretically. Conclusions about common principles depend on the degree to which the separate schedules can be discriminated by the

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subject, and the source of responses can be distinguished by the experimenter.

The basis for differentiating alternatives need not be external stimuli. If the components of conjoint schedules involve different temporal definitions of response, choice can occur and be identified. A series of experiments (Shimp, 1975) arranged reinforcers concurrently for two different interresponse times. Performance in both conjoint and multiple-response schedules was readily explained as involving choice between the alternatives. The correlation of different temporal response definitions with the reinforcer operates similarly to external stimuli in delineating the sources of reinforcement. Choice, then, may operate and be observed when a given response is either temporally or topographically compatible with only one of the paths to the same goal. The tempting generalization is that all forms of concurrent schedules involving distinctive alternatives may reflect choice between the options.

This conclusion may be premature. In Shimp's procedures, not only would any sort of unified compromise behavior fail to produce any reinforcers, but each reinforcer delivery was assigned to only one of the alternatives. Choice was the only form of behavior that could be reinforced. Therefore, choice may typify only such highly constrained conjoint schedules. The generalization above may be tested by a conjoint schedule in which the alternatives differ but choice is not compelled.

A conjoint random-interval (RI) differential-reinforcement-of-low-rate (DRL) schedule has the desired properties. The RI imposes no timing requirement on response spacing, but the DRL demands that a specified time elapse between responses for a reinforcer to occur. One possibility is that a single component could control behavior exclusively. A second is that reinforcer frequencies would be integrated in accordance with the absolute-rate matching law. A third is that performance would reflect choice between the two alternatives. To assess these possibilities, nominal reinforcer frequencies for the two alternatives were varied by changing the number of components to be completed per reinforcer. These second-order fixed-ratio schedules altered scheduled reinforcer frequency without changing the DRL timing requirement. In addition, differ-

ent DRL time parameters showed the effect of the response-spacing feature.

EXPERIMENT 1

METHOD

Subjects

Five White Carneaux pigeons were maintained at 80% of their free-feeding weights. All had experience with a variety of reinforcement schedules and discriminative stimuli.

Apparatus

The response key was 2 cm in diameter and operated with a minimum force of .18 N. The key could be transilluminated by two 7-W red or blue lamps. A 5-cm square aperture centered 8 cm below the key provided occasional 3-sec access to Purina Pigeon Checkers, the birds' standard diet. The aperture was illuminated by a 1-W white lamp during feeder cycles. A houselight provided dim general illumination. Continuous white noise helped mask extraneous sounds. Experimental events were controlled and recorded by an on-line computer.

Procedure

The schedule was either random interval (RI), differential-reinforcement-of-low-rate (DRL), or conjoint RI DRL. A second-order fixed-ratio (FR) schedule specified the number of requirements of a given type to be completed per food delivery. No stimulus event followed completion of any but the final requirement; the key was red until the FR was completed and then food was presented. In the conjoint schedules, the FR schedules for the RI and DRL components were independent. For example, if both components had FR 4 second-order schedules, food was obtained as soon as the fourth component of a given type was completed. The FR counter for the schedule yielding the food delivery reset to zero, but the other counter was unchanged. The only lack of independence was that the RI schedule was suspended when the DRL timed out, and any RI completion that could be produced by the next response was lost if the DRL timed out before that response occurred. The RI component always had a mean interval of 1 min (determined by a pulse every second into a probability gate), and the DRL time was

Table 1
Sequence of Conditions: Experiment 1
(Number of Sessions)

Condition	Bird 101	Bird 107	Bird 140	Bird 148	Bird 157
1	4DRL 10 (27)	2RI (12)	2RI (10)	4RI 2DRL 10 (26)	4RI (10)
2	4RI (12)	4RI (12)	16RI (12)	2RI (11)	8RI (12)
3	4RI 1DRL 10 (21)	2RI 1DRL 10 (23)	4RI (11)	8RI (10)	2RI 1DRL 20 (14)
4	4RI 1DRL 20 (22)	1DRL 20 (26)	1RI 1DRL 10 (21)	1DRL 20 (12)	4RI 1DRL 20 (12)
5	16RI (12)	4RI 1DRL 10 (17)	4RI 1DRL 10 (24)	4RI 1DRL 20 (24)	8RI 1DRL 20 (10)
6	2RI (18)	8RI 1DRL 20 (16)	8RI 1DRL 10 (13)	8RI 1DRL 20 (21)	16RI 1DRL 20 (13)
7	1DRL 10 (15)	8RI (11)	1RI (10)	8RI 2DRL 10 (17)	8RI 1 DRL 10 (29)
8	4RI 4DRL 10 (18)	16RI 1DRL 20 (20)	1DRL 20 (15)	8RI 4DRL 10 (26)	8RI 2DRL 10 (31)
9	8RI 1DRL 20 (29)	2DRL 10 (14)	16RI 1DRL 20 (28)	8RI 2DRL 20 (13)	8RI 4DRL 10 (14)
10	8RI (14)	8RI 2DRL 10 (19)	8RI 2DRL 10 (29)	4RI 2DRL 20 (10)	1RI (12)
11	1DRL 20 (41)	8RI 4DRL 10 (14)	2DRL 10 (16)	4RI 4DRL 10 (12)	2RI (11)
12	16RI 2DRL 20 (17)	4DRL 10 (14)	8RI 4DRL 10 (24)	2RI 1DRL 10 (18)	1DRL 10 (26)
13	2DRL 20 (15)	2DRL 20 (13)	2DRL 20 (15)	2RI 2DRL 10 (11)	2DRL 10 (14)
14	8RI 2DRL 20 (13)	8RI 2DRL 20 (11)	8RI 2DRL 20 (26)	2DRL 10 (24)	4DRL 10 (14)
15	8RI 4DRL 10 (15)	16RI 2DRL 10 (24)	16RI 2DRL 20 (11)	4RI (10)	1DRL 20 (17)
16	2DRL 10 (10)	2RI 2DRL 10 (31)	1DRL 10 (17)	1RI (12)	2DRL 20 (10)
17	4RI 2DRL 10 (19)	4RI 1DRL 20 (24)	1RI 1DRL 20 (11)	1DRL 10 (11)	8RI 2DRL 20 (19)
18	16RI 1DRL 10 (13)	1RI (11)	16RI 1DRL 10 (15)	4DRL 10 (19)	2RI 1DRL 10 (12)
19	8RI 2DRL 10 (11)	1DRL 10 (14)	4DRL 10 (14)	2DRL 20 (14)	4RI 1DRL 10 (27)
20	8RI 1DRL 10 (12)	8RI 1DRL 10 (16)	8RI 1DRL 20 (18)	8RI 1DRL 10 (22)	4RI 2DRL 10 (18)

either 10 or 20 sec. Table 1 shows the sequence of conditions.

Each condition continued until performance met a stability criterion. The median response rate was calculated for sliding blocks of three sessions. Performance was considered stable when three successive medians (involving nine consecutive sessions) differed by no more than 10% and showed no monotonic direction of change.

Sessions were conducted five days per week. Through Condition 5, sessions terminated after 30 food deliveries or 2 hr, whichever occurred first. Subsequently they also ended after 1500 responses because of equipment limitations in recording large numbers of inter-response times.

RESULTS AND DISCUSSION

Figure 1 shows representative interresponse-time distributions for the simple RI schedules, the simple DRL schedules, and for the conjoint schedules. The RI schedules alone produced distributions peaked at interresponse times between 1 and 3 sec no matter how many components had to be completed per reinforcer delivery. The DRL distributions were flatter than those for RI, and they peaked below the interresponse time necessary for re-

inforcement. Conditional-probability distributions peaked at 6 to 8 sec with the DRL 10-sec schedules. The DRL 20-sec distributions were flatter than those of DRL 10 sec with broad peaks extending from 10 to 15 sec. The second-order FR schedule had no apparent effect on the form of the distributions.

The conjoint schedules yielded one peak near that characteristic of the RI schedule and a second around that of the DRL. Once again, the second-order FR schedules had no apparent effect, except that the heights of the two peaks changed as the proportion of reinforcers obtained from each component changed. The higher the proportion associated with a given source, the higher was the peak for that source. If changes in reinforcer proportions were taken into account, the conjoint schedules appeared to maintain the two types of behavior occurring with the two component schedules. Sequential effects were not apparent. An RI or DRL schedule completion was equally likely to occur whether the previous completion had been RI or DRL or whether a reinforcer had been obtained from either source.

All analyses were based on data combined over the last five sessions of each condition. These data appear in Table 2.

Figure 2 shows response rate as a function

Fig. 1. Representative interresponse-time distributions (interresponse times per opportunity and relative probability). Interresponse times 21-sec and longer appear in Bin "d." Data are for Bird 148: FR 4(RI), FR 2(DRL 10-sec), and conjoint FR 4(RI) FR (2DRL 10-sec).

of reinforcer frequency for the simple RI schedules together with those of the conjoint schedules producing all reinforcers via the RI component. It also provides the same information for the simple DRL schedules. (No conjoint schedule yielded exclusive DRL reinforcers.) Both sets of data indicated a positive relation between response rate and reinforcer rate. Indeed, response rate in the DRL schedules was better related to reinforcer rate than to the DRL time value. The absolute-rate matching law was fit to the data using the equation:

$$R_1 = \frac{kr_1}{r_1 + r_e}, \quad (1)$$

where R_1 was response rate, r_1 was the frequency of reinforcement for the measured response, and k and r_e were fitting parameters. Accuracy of fit compared to that found elsewhere (de Villiers, 1977). Percent variance accounted for was determined using the method described by McDowell (1981), which allows

exact test of the accuracy of prediction. The k parameter always was higher for RI than for DRL, and r_e usually was higher for DRL.

Although some experimenters have found good temporal control with DRL schedules in pigeons (e.g., Richardson & Loughhead, 1974), others have not (e.g., Reynolds, 1966). The possibility that reinforcer density was determining responding in the absence of temporal control has not been investigated. The present data suggest that an interaction between the timing requirement and reinforcer frequency determined DRL performance (if it were reinforcer frequency alone, the matching law fits to the RI and DRL baseline data would have had similar parameters).

In the remaining conjoint schedules, reinforcers occurred from both the RI and DRL components. The effect of increased DRL reinforcers was to decrease overall response rate. The absolute-rate matching law predicted this general effect only if the RI component was the source of reinforcement for pecking, but both components contributed to overall reinforcer frequency. The absolute-rate matching law assumed the form:

$$R_1 = \frac{kr_1}{r_1 + r_2 + r_e}, \quad (2)$$

where R_1 is overall responses per minute (the sum of both RI and DRL response rates), r_1 is reinforcers per hour from RI, and r_2 is reinforcers per hour from DRL. Figure 3 shows the outcome of this conceptualization. Percent variance accounted for in individual subjects ranged from -70% to +87%. Negative percentages occur when obtained response rates have less variance than do the differences between predicted rates. It means that the range in the dependent variable was too small to permit meaningful evaluation. When the data were grouped, percent variance accounted for was 79%.

Comparison of Figures 2 and 3 provides a source of concern in approaching the data in terms of the absolute-rate matching law. Figure 3 and the left column of Figure 2 both deal with response rate controlled by the RI schedule. Differences in r_e for each bird are interpretable as the outcome of the presence or absence of a DRL schedule, although one might expect that r_e for the conjoint schedules would lie somewhere between those for the simple RI and DRL schedules, when in fact

Table 2
Data: Experiment 1

Cond	Bird 101				Bird 107				Bird 140			
	Time (Sec)	Resp	Reinf RI DRL		Time (Sec)	Resp	Reinf RI DRL		Time (Sec)	Resp	Reinf RI DRL	
1	35829	5868	—	57	19651	10218	150	—	18401	12267	150	—
2	35550	15598	150	—	35711	17022	144	—	35892	19899	36	—
3	15395	4721	64	86	13023	5852	98	52	35559	22368	147	—
4	21448	7757	89	61	26498	2285	—	150	9926	7802	140	10
5	35892	13809	36	—	32682	18411	134	16	31892	22004	132	18
6	16504	7500	135	—	13636	7500	26	1	8721	1543	3	147
7	25912	7500	—	145	15789	7500	32	—	8978	6785	150	—
8	17375	7500	73	0	16917	7500	17	2	32335	3472	—	150
9	21428	7500	42	5	12843	1806	—	150	12430	7500	12	2
10	18031	7500	37	—	13262	2685	24	126	8883	1625	16	134
11	35805	6801	—	65	18787	7500	36	35	10222	1681	—	150
12	18828	7500	19	0	22053	2533	—	150	19121	7500	37	46
13	35874	5677	—	42	35643	2772	—	119	35689	3104	—	107
14	18075	7500	37	3	16014	7500	30	0	11726	7500	19	1
15	19565	7500	37	14	15527	3676	12	138	12288	7500	12	0
16	35622	7280	—	126	14804	7500	121	20	9061	1557	—	150
17	23684	7500	98	20	14605	7500	58	0	8984	6468	150	0
18	30720	7500	32	114	9008	5294	150	—	8947	1521	2	148
19	21429	7500	39	17	6594	945	—	150	25835	3684	—	150
20	26880	6944	56	94	6261	1106	13	137	11260	7500	22	1

Cond	Bird 148				Bird 157			
	Time (Sec)	Resp	Reinf RI DRL		Time (Sec)	Resp	Reinf RI DRL	
1	23354	7807	90	60	35556	24010	148	—
2	18203	11377	150	—	35778	22321	74	—
3	35798	18844	74	—	20894	14575	148	2
4	35826	5330	—	58	35444	21243	143	7
5	31713	16878	142	8	13006	7500	24	0
6	16067	7500	30	12	13473	7500	13	1
7	24456	7500	45	42	9525	1936	18	132
8	24228	7500	48	27	11064	2988	20	130
9	13719	7500	27	2	13126	7500	26	6
10	13393	7500	55	0	9104	6507	150	—
11	14955	7500	60	2	11194	7500	95	—
12	16277	7108	122	28	16434	2706	—	150
13	13611	7500	112	1	23334	3639	—	150
14	35489	7005	—	137	34438	5140	—	150
15	13158	7500	53	—	35874	4623	—	42
16	9092	5682	150	—	35913	4024	—	29
17	22395	4722	—	150	13536	7500	27	2
18	35703	5766	—	99	12124	7500	100	2
19	35907	4838	—	31	16420	4680	65	85
20	15845	3795	31	119	16605	7500	59	21

this was not always true. A negative r_e , as sometimes occurred with the conjoint schedules, also seemed peculiar. More important are the differences in k . If k is the maximum rate attainable with the RI schedule, the values should be constant for each bird for the simple RI and conjoint conditions. Yet, for three of the five birds, k was substantially larger for the conjoint schedules. Whether these differ-

ences reflect sampling error, the inclusion of both RI and DRL response rates in R_1 , or theoretical inadequacy is unclear.

Another approach was to consider the conjoint schedules as involving choices between the two components. The hypothesis was that the birds allocated time between the components in the same proportion as reinforcers were distributed. The further assumption of

Fig. 2. Matching law fits to component schedules. Fitting parameters and percent variance accounted for appear in each graph.

this model (referred to here as the *rate constancy model*) was that when choosing an alternative, the pigeon responded at the same rate as when that schedule prevailed alone. (If the component schedule never had appeared alone, the rate was predicted from the matching-law parameters of Figure 2.) Predicted rate in the conjoint schedules, then, was the weighted sum of the two baseline rates (RI and DRL), with the weights being the proportion of reinforcers. The model is:

$$R = p B_1 + (1 - p) B_2, \quad (3)$$

where R is response rate, p is the proportion of reinforcers for RI, and B_1 and B_2 are the baseline rates for the RI and DRL schedules respectively. Figure 4 shows the relation between predicted and obtained rates.

The model accounted for 8% to 93% of the variance in obtained rates for the individual pigeons. Once again, the poorest fits occurred when obtained rates varied over a small range. The percent variance accounted for by grouping the data was 85%. Not only was this higher than the percentage accounted for by grouping the data of Figure 3, but with four of the

Fig. 3. Relation between obtained rates in conjoint schedule and rates predicted from matching law (Equation 1). Fitting parameters and percent variance accounted for appear in each graph.

Fig. 4. Rate constancy model fits to conjoint schedule response rates (Equation 2). Percent variance accounted for appears in each graph.

five pigeons more variance was accounted for by the rate constancy model than by the absolute-rate matching law. This form of conjoint schedules therefore appeared to involve choice between schedules.

EXPERIMENT 2

The data of Experiment 1 were interpreted as involving choices between the two components. Experiment 2 further explored this interpretation with the DRL schedule changed by adding a visual stimulus that indicated when the DRL time requirement had elapsed. Perfect control by this external clock would mean that the pigeons would respond on the DRL schedule only when the interresponse time met the time requirement. If the RI schedule again produced the peaked distributions of Experiment 1, but the DRL yielded a narrow distribution peaked sharply at the time that signaled that the interval had elapsed, the component distributions would overlap to a lesser extent than before. If the conjoint schedules involved choice, they should reveal the persistence of the two distributions. Second-order fixed-ratio schedules allowed changes in nominal reinforcer frequency without changing the timing requirement, and different DRL time parameters showed the effect of the required interresponse time. Fixed ratios of 1, 2, and 4 applied to each component yielded two factorial designs, one for RI and DRL 10-sec and the second for RI and DRL 20-sec.

Little is known about the effects of clocks on DRL performance. Reynolds and Limpo (1968) found that a clock reduced premature responding, but some early responses did occur. In contrast, clocks eliminated early responding with timing requirements imposed on extended response sequences (DeCasper & Zeiler, 1974). The present experiments appear to be the first to study the effects of a clock on DRL performance over a range of conditions.

METHOD

Subjects and Apparatus

The subjects and apparatus were the same as in Experiment 1.

Procedure

The procedure resembled that of Experiment 1. The major difference was that a stimulus change signaled when the pigeons had

paused long enough to meet the DRL requirement in both the simple DRL schedules and the conjoint RI DRL schedules. The key color changed from red to blue when the pause was sufficiently long. The next response was followed either by the key color changing back to red, or by food delivery if the FR second-order schedule had been completed. No stimulus event signaled either when the RI had timed out or when an RI component was completed, except that the completion that met the FR requirement resulted in food delivery.

Table 3 shows the sequence of conditions. For the conjoint schedule, all birds had FR 1, 2, and 4 second-order schedules applied to both the RI and DRL components according to a factorial design. Separate factorial designs involved DRL values of 10 and 20 sec. The conjoint schedules constituted Conditions 1 to 18 and were conducted in the same order for all

Table 3
Sequence of Conditions: Experiment 2

Condition	Schedule	Sessions
1	4RI 1DRL 10	21
2	2RI 1DRL 10	23
3	1RI 4DRL 20	20
4	1RI 1DRL 20	15
5	2RI 1DRL 20	7
6	4RI 1DRL 20	8
7	4RI 2DRL 10	8
8	4RI 2DRL 20	9
9	2RI 2DRL 10	15
10	2RI 4DRL 10	13
11	1RI 1DRL 10	21
12	1RI 2DRL 10	11
13	4RI 4DRL 10	17
14	1RI 4DRL 10	12
15	1RI 2DRL 20	13
16	2RI 2DRL 20	11
17	2RI 4DRL 20	15
18	4RI 4DRL 20	11

Schedule	Condition (Sessions)				
	Bird 101	Bird 107	Bird 140	Bird 148	Bird 157
1DRL 10	21 (10)	21 (10)			22 (10)
2DRL 10	23 (14)	23 (14)	20 (11)	20 (11)	23 (14)
4DRL 10	24 (26)	24 (26)	22 (10)		20 (11)
			24 (26)		
1DRL 20	20 (11)	20 (11)	23 (14)	21 (10)	24 (26)
2DRL 20	19 (20)	19 (20)	19 (20)	22 (10)	19 (20)
4DRL 20	22 (10)	22 (10)	21 (10)	19 (20)	21 (10)
1RI	26 (15)	25 (17)	27 (17)		25 (17)
2RI	27 (17)	27 (17)	25 (17)		27 (17)
4RI	25 (17)	26 (15)	26 (15)		26 (15)

birds. Conditions 19 to 27 were conducted in different orders. These involved FR 1, 2, and 4 second-order schedules with RI, DRL 10-sec, and DRL 20-sec schedules in effect alone. Bird 140 never had the FR 1(DRL 10-sec) schedule but had the FR 2(DRL 10-sec) twice due to experimenter error. Bird 148 became ill and was discontinued after Condition 22.

Sessions were conducted seven days per week. Each condition lasted until response rate showed no monotonic change over five sessions for all birds. Sessions terminated after 30 food deliveries or 1500 responses, whichever occurred first.

RESULTS AND DISCUSSION

Figure 5 shows representative interresponse-time distributions for the RI schedule in effect alone, the DRL schedule in effect alone, and the conjoint schedule. The RI schedules always produced distributions sharply peaked at interresponse times between 1 and 3 sec.

Fig. 5. Representative interresponse-time distributions (interresponse times per opportunity and relative probability). Interresponse times 21-sec and longer appear in Bin "d." Data are for Bird 101: FR 1(RI), FR 2(DRL 10-sec), and conjoint FR 1(RI) FR 2(DRL 10-sec).

The DRL schedules resulted in almost all responses occurring after the required pause. The forms of the distributions were the same under all FR second-order schedules. The DRL 10-sec conditions produced sharp peaks at between 10 and 12 sec; DRL 20-sec schedules produced equally sharp peaks between 20 and 22 sec.

The conjoint schedules did not maintain the two component distributions intact, but usually generated some interresponse times intermediate between those yielded by the component schedules alone. Also, interresponse times in the smallest bin often increased over the level generated by either component alone. Despite the intermediate times, the conjoint schedule distributions were clearly bimodal, with peaks at the values characteristic of the two components. Behavior in the conjoint schedules consisted mainly (but not solely) of the two forms appearing in the component schedules. As in Experiment 1, no sequential dependencies described when a given interresponse time occurred.

In conditions producing exclusive reinforcement from one source, session-to-session response rates differed by no more than 10% from the mean rates over five sessions. Variability increased as the proportion of reinforcers obtained from each source approached equality. Rates for each member of each group of five sessions differed by as much as 40% from the mean, and variability was not reduced by additional sessions. Despite between-session variability, mean rates over any group of five successive sessions varied nonmonotonically by 10% or less. Table 4 shows the data over the last five sessions of each condition.

The absolute-rate matching law involving one known source of reinforcement (Equation 1) was fit to the data of the conditions yielding exclusive RI or DRL reinforcers. Percent variance accounted for ranged from 3% to 57% for the RI schedules and from 3% to 40% for the DRL schedules. The values of k and r_e respectively for the RI conditions were: Bird 101: 37.5, 6.3; Bird 107: 31.0, 0.1; Bird 140: 61.5, 6.4; Bird 148: 54.8, 1.0; Bird 157: 52.2, 2.3. For the DRL conditions k and r_e were: Bird 101: 5.7, 25.0; Bird 107: 5.7, 34.3; Bird 140: 4.3, -3.2; Bird 148: 6.2, 53.7; Bird 157: 5.9, 34.5. Once again the two parameters varied with the schedule, with k always higher for RI than for DRL, and r_e usually higher

Table 4
Data: Experiment 2

Cond	Bird 101				Bird 107				Bird 140			
	Time (Sec)	Resp	Reinf		Time (Sec)	Resp	Reinf		Time (Sec)	Resp	Reinf	
			RI	DRL			RI	DRL			RI	DRL
1	1788	165	0	150	1772	153	0	150	1836	151	0	150
2	1737	164	3	147	1710	152	0	150	1705	155	1	149
3	8342	5143	150	0	7948	4003	150	0	7645	7500	78	0
4	9473	5536	150	0	8445	4856	150	0	7397	7500	122	0
5	14580	7500	123	0	14749	7500	123	0	8971	7500	71	3
6	20437	7500	81	24	17857	7500	70	19	9754	7500	39	1
7	5679	1372	18	132	5592	1597	19	131	4151	828	14	136
8	20191	7500	83	20	16013	7500	56	0	9989	7500	45	2
9	10817	4048	81	69	4482	559	28	122	3354	766	31	119
10	16593	6679	123	17	12435	5152	100	49	8891	7500	58	9
11	2615	622	37	113	1623	335	25	126	1772	413	25	125
12	4926	1837	76	74	2972	556	44	106	3317	1032	51	99
13	9868	2795	34	116	9369	2279	31	119	12438	4975	45	102
14	2759	3079	120	30	7335	3256	113	37	8162	5487	131	17
15	8720	4467	150	0	10877	5635	150	0	8121	7138	134	3
16	17001	7500	147	0	15328	7500	129	0	9074	7500	73	0
17	13697	7500	110	0	15646	7500	117	0	10019	7500	78	0
18	17802	7500	69	8	17307	7500	68	14	10660	7500	46	0
19	7266	430	—	150	6305	316	—	150	6233	360	—	150
20	3231	162	—	150	3078	150	—	150	3243	318	—	150
21	1598	157	—	150	1548	150	—	150	12984	648	—	150
22	13766	721	—	150	12583	635	—	150	6762	640	—	150
23	3384	310	—	150	3447	312	—	150	3092	152	—	150
24	7451	730	—	150	6441	637	—	150	6520	667	—	150
25	16187	7500	69	—	8498	3794	150	—	8428	7500	69	—
26	9683	5574	150	—	13295	7500	55	—	10112	7500	40	—
27	14299	7500	130	—	12470	7500	104	—	7901	6403	142	—

Cond	Bird 148				Bird 157			
	Time (Sec)	Resp	Reinf		Time (Sec)	Resp	Reinf	
			RI	DRL			RI	DRL
1	1639	150	0	150	3130	573	8	142
2	1611	150	0	150	4797	1142	30	120
3	8428	7500	150	0	8480	6456	150	0
4	8428	7212	150	0	9286	7500	145	0
5	8113	7500	74	0	9545	7500	90	0
6	11555	7500	46	5	10497	7500	39	6
7	4206	821	7	143	7544	2713	25	122
8	17130	7500	58	41	10035	7500	41	0
9	3283	695	24	126	10055	7500	80	4
10	11254	4855	92	44	9916	7500	84	1
11	1569	334	22	128	7913	6020	148	1
12	3078	841	45	105	8086	6639	138	0
13	9523	2213	28	122	12900	7469	57	36
14	8942	7035	141	1	7806	6778	137	0
15	7638	7325	125	0	8516	7315	150	0
16	9095	7500	81	0	9504	7500	81	0
17	8333	7500	69	0	9865	7500	82	0
18	12510	7500	46	8	9847	7500	42	0
19	12675	692	—	150	6818	389	—	150
20	3222	336	—	150	6387	622	—	150
21	3052	150	—	150	12663	639	—	150
22	6234	333	—	150	1582	150	—	150
23					3174	304	—	150
24					3246	165	—	150
25					7812	7500	112	—
26					9509	7500	37	—
27					9376	7500	72	—

for DRL. The fits were less accurate than in Experiment 1. The reason for the poor fits with DRL was evident: Response rate was determined by the DRL time parameter and not by reinforcer frequency. The cause of the poor fits with RI was not apparent.

Equation 2 (absolute-rate matching law with RI reinforcer frequency in the numerator and total reinforcer frequency in the denominator) was applied to the conditions producing a mixture of RI and DRL reinforcers. The obtained k , r_e , and percent variance accounted for were: Bird 101: 44.5, 11.3, 18%; Bird 107: 44.9, 7.5, 47%; Bird 140: 56.2, 2.4, 93%; Bird 148: 51.9, 4.2, 86%; Bird 157: 48.4, -0.2, 79%. Grouped data showed that the equation accounted for 85% of the variance. As in Experiment 1, k was not the same for these conjoint schedules as for those producing exclusive RI reinforcers, even though in both cases k presumably represented maximum RI rate.

Figure 6 shows the results of the rate-constancy analysis (Equation 3). The proportion of time allocated to a component was presumed to match the proportion of reinforcers obtained in that component. When choosing an alternative, the birds were assumed to respond at the same rate as when that schedule prevailed alone. Each component rate was taken as the average rate produced by that schedule in all conditions where it controlled all reinforcers. For Bird 140, which never had an FR 4(RI) schedule that produced exclusive RI reinforcers, baseline rate for that component was deduced from the best-fitting matching-law parameters. That bird also never had a condition involving FR 4(DRL 10-sec) that produced exclusive DRL reinforcers. The best estimate derived from the other pigeons was that this baseline rate could be approximated as the mean rate over the other DRL 10-sec exclusive reinforcer conditions. The fits of Figure 6 accounted for between 63% and 93% of the variance in response rates. The worst fits occurred when the response rates fell in a small range (Birds 101, 107) so that little variance existed to be accounted for. The grouped data showed that the rate constancy model accounted for 90% of the variance.

The assumption of perfect matching of time allocation to reinforcer frequency in the rate constancy model could have been demonstrated incorrect had the interresponse-time distributions of the component RI and DRL

schedules shown no overlap and had the conjoint schedules precisely combined these two distributions. Then the percentage of time allocated to each component would be known, and its relation to reinforcer allocation could be determined. Because the components always entailed different amounts of time allocation per reinforcer, time-allocation proportions could not have matched reinforcer proportions. For example, with the FR 1(RI) FR 1 (DRL 10-sec) schedule, food delivery would occur after 10 to 12 sec in the DRL component but would require an average of 60 sec in the RI. Other schedule combinations differ in specifics, but all share an imbalance in time per component per reinforcer. However, the component distributions did overlap somewhat, and the conjoint schedules generated interresponse-time distributions different from those of its components. If most of the new intermediate interresponse times actually were DRL times, time allocation closely matched reinforcer allocation. This would mean that the addition of the RI component to the DRL induced early responding on some occasions that the bird had chosen the DRL alternative. Early responding could stem from the feedback relations inherent in RI schedules. If the pigeons had chosen the DRL component, as time passed, the possibility of an RI reinforcer being available increased. This feature could induce switching from DRL to RI, where time before the switch actually was being allocated to DRL.

Incorrect predictions would have occurred if either of the underlying assumptions—time-allocation matching and maintained baseline rates—was incorrect and the other was correct. What remains possible is that both assumptions are wrong, and that the apparent ability to account for the data stems from complementary deviations in both assumed processes.

Figure 7 shows the absolute rate of reinforcement for each schedule for each cell of the factorial design involving DRL 10-sec components. The curves were erratic but roughly indicated that reinforcers per hr from one source decreased as the FR second-order schedule applied to the other decreased. The DRL 20-sec components showed the same relation, except that DRL reinforcers per hr were zero in many cases. Overall reinforcer frequency would have been maximized had the DRL baseline performance been maintained in all

Fig. 6. Rate constancy model fits to conjoint schedule response rates (Equation 2). Percent variance accounted for appears in each graph.

Fig. 7. Obtained reinforcer frequency for each component in the conjoint schedules. The three curves in the left panels are for FR 1, 2, and 4 of RI; those in the right panels are for FR 1, 2, and 4 of DRL 10-sec. Vertical scales differ in each column.

conjoint schedules except FR 1(RI) FR 4(DRL 20-sec). In that case, the RI could provide about 60 food presentations per hr, whereas the DRL could produce 45 per hr at best. In all other conditions, the DRL schedule could produce the higher frequency with the advantage ranging from 345 reinforcers per hr in conjoint FR 4(RI) FR 1(DRL 10-sec) to 15 reinforcers per hr in conjoint FR 2(RI) FR 4 (DRL 20-sec). Figure 8 shows the overall frequency in the conjoint schedule as percentages of the maximum possible had responding been confined to the component providing the

Fig. 8. Grouped data. Obtained reinforcer frequency in the conjoint schedules as percentage of frequency that could be obtained if responding was confined to the more favorable alternative. The more favorable alternative was DRL except for the point indicated by the arrow.

higher reinforcer frequency in the baseline conditions. In some individual cases, possible and obtained frequencies corresponded, but overall the individual birds led to the same conclusion as did the averaged data. The pigeons did not obtain as high a frequency as they would have gotten by choosing only the DRL alternative. They did get as much or more food than they would have received by confining themselves to the RI, but they would have achieved a considerably higher frequency of food delivery had they restricted choice to the DRL. In the one case where the RI baseline frequency was higher than DRL, responding indeed was confined to RI.

GENERAL DISCUSSION

Performance in the present conjoint schedules appeared to represent choice between the two schedule components (between the two different ways of emitting the same response). The conjoint RI DRL schedules seemed equiv-

alent to multiple-response concurrent schedules in that the pigeons always were choosing between the alternatives.

A problem for analysis in terms of the absolute-rate matching law is that the k parameter for the conjoint and simple RI schedules was not the same and was higher in the conjoint schedules of Experiment 2 than in those of Experiment 1, even though k presumably indicated maximum response rate under RI. This would imply that k represents not a fixed maximum rate but one that varies with experimental procedure. The second problem—a conceptual one—seems more serious. The DRL schedule also reinforced key pecking, so that some of the responses had to be attributed to that component. Indeed, the bimodal interresponse-time distributions showed that responding was controlled by two sources. Yet the analysis treated DRL as involving something else. (When the DRL was considered as a separate source of pecking by adding DRL to RI reinforcer frequency in the numerator of Equation 2, the predictions corresponded poorly with the data. Such an account could not possibly be correct, because it would be asserting that the same overall frequency of reinforcement would produce the same response rate regardless of how the reinforcers were divided between RI and DRL.) This might explain the differences in k with the RI and conjoint schedules, but it does not sidestep the principle that the analysis acts as if all pecks were generated by the RI component. In short, this form of the absolute-rate matching law succeeds only by doing violence to the nature of the procedure and data. Either performance did not represent integration of the two sources of control, or the integration principle is not the absolute-rate matching law. The rate constancy model does not share any of these problems and, in addition, accounts for a higher percentage of the data variance. Further, it does so without having to introduce bias and undermatching or overmatching—perfect time-allocation matching to reinforcement frequency is assumed.

In conjoint schedules involving DRL components with clocks, Shimp (1969) concluded that relative response frequency matched the relative harmonic length of the required interresponse times when the relative reinforcer frequencies were equal in the two components. Although the rate constancy model has thus

far been applied to overall response rates, it also predicts relative response frequencies. Response rate in each individual component is the baseline rate multiplied by the percentage of reinforcers correlated with that component. This yields a predicted rate for each component and thereby allows prediction of relative rates. Shimp reported no baseline data; however, Experiment 2 suggests that one response would have occurred just after the clock signaled that the DRL requirement had elapsed. Baseline rates, then, would be approximately $1/\text{DRL}$ value, or the same as the harmonic length of the DRL time parameter. If the pigeons allocated time to the two components in the same proportion as they received reinforcers (.5), the relative number of responses in each component would match the relative harmonic length because of the correspondence between that measure and the baseline rates. The model also predicts well the exact values of the points falling on the increasing negatively-accelerated curve relating relative response rate to relative reinforcer frequency when the latter was varied parametrically (Shimp & Hawkes, 1974). In addition, the ability to explain Experiments 1 and 2 with the same model supports the contention (Shimp & Hawkes, 1974) that the same choice principles operate with DRL components with and without added clocks.

The alternative is to deal with Shimp and Hawkes' response data in terms of the matching law for choice (Baum, 1979). The data can be well described as showing biased undermatching. This then entails the need to explain why one aspect of behavior (time allocation) shows perfect matching and no bias, whereas another (response allocation) reveals both bias and deviation from perfect matching. The present answer is that the problem stems from misconceptions about response allocation. It is not in itself fundamental; time allocation matching is the underlying choice process. Response allocation is the byproduct of time matching and the persistence of responding as if no other component existed.

The success of the rate constancy model suggests that conjoint schedules with different response units involve choice between the alternatives rather than any sort of blending of response rates or reinforcer frequencies into a single type of performance. Multiple-response concurrent schedules involve choices between

response units, on the assumption that part of the definition of a response is the stimulus controlling its presence. Based on data from a number of experiments, Shimp (cf. Shimp & Hawkes, 1974) has insisted that the two types of concurrent schedules involve identical processes. If the rate constancy model holds in general, precise matching of relative response rates to relative reinforcer frequencies in multiple-response concurrent schedules should occur only when the components have equal baseline rates. Data for evaluating this assertion are not readily available, because concurrent schedule experiments seem never to have studied the necessary baseline conditions. With multiple-response concurrent DRL/DRL schedules (Moffitt & Shimp, 1971), relative response frequency matched the relative harmonic means of the DRL time values. If baseline rates varied in approximately the same ratios as did the harmonic means of the required interresponse times (this assumption conforms to what is known about DRL performance when behavior is under temporal control), the rate constancy model describes the response data. Additional tentative conclusions are based on the assumption that reported local response rates correspond to baseline rates. In one study (Silberberg & Fantino, 1970) local rates were not related in an orderly way to schedule parameters, and the model predicts the obtained undermatching of response rates. Undermatching perhaps is a product of unstable performance. (Such irregularity may not be uncommon: A poor relation between schedule parameter value and local response rate has appeared in other concurrent schedule research—e.g., Bacotti, 1977.) Other studies have used components likely to yield higher rates in one component. Then the model predicts the bias in favor of the higher-rate component that has been observed with VI and FI (Trevett, Davison, & Williams, 1972), with VI and VR (Herrnstein and Loveland, cited in de Villiers, 1977), and with VR and FI (Rider, 1981). A VI is likely to produce a higher rate than FI, and VR a higher rate than either VI or FI. These experiments showed the biases predicted by the model.

Concurrent VI/FR data seem to be a problem. Because local response rates are higher in FR than VI, bias towards the FR is expected. Davison (1982), using three-component schedules, reported such bias when the FR was con-

sidered in relation to total VI responding. However, Bacotti (1977) obtained bias for the VI, and Davison (1982) suggested that the direction of bias might depend on the VI parameter value. A possible way to reconcile these data with the rate constancy model is by modifying the time-allocation aspect. The p of Equation 3 can be taken as a function of reinforcer proportions rather than as the proportion itself. Biased time allocation can be incorporated by recognizing that:

$$\frac{p}{1-p} = c \left(\frac{r_1}{r_2} \right)^a, \quad (4)$$

where c and a are fitting parameters, and r_1 and r_2 are the number of reinforcers derived from Sources 1 and 2 respectively. Equation 4 yields the value of p to be used in Equation 3. In the cases conforming to the original model, both c and a equal 1.0; for the concurrent VI/FR results they do not. The advantage gained by this approach must be weighed against the decreased predictive power entailed by fitting parameters and abandonment of the perfect matching hypothesis. It might be better simply to recognize that FR schedules (the only ones so far to challenge the original model) have a number of well-documented unique effects (cf. Zeiler, 1979). These may stem from the nature of the response unit established by FR schedules and also from interference with the original unit when these schedules are combined with others. If time-allocation matching actually refers to time devoted to response units, the presently-described anomalies might disappear.

Attempts to measure time allocation encounter both procedural and conceptual difficulties. If time allocation is assessed with both schedules imposed simultaneously, there is no firm basis for estimating how much time is being spent in either. The assumption is that time spent in a component is properly considered as the time from the first response in that component to the first in the other. Yet many schedules produce pauses before the first response. This measurement strategy improperly assigns those pauses to time spent in the other component. The changeover key procedure (Findley, 1958) might seem a better way of determining time allocation. However, even there time allocation is not determined readily. Stimulus changes themselves may be reinforcing (Appel, 1963). Thus, in either form

of multiple-response schedule the animal may make a changeover response simply to change stimuli without actually choosing to be in the other schedule. Some of the time attributed to a schedule actually may be dead time allocated to neither schedule. Such effects would indicate time mismatching when in fact functional time allocation perfectly matches reinforcer allocation. No ready solution to these problems is apparent; the requirement is separation of functional from recorded time.

A consistent finding of Experiment 2 was that the pigeons rarely optimized reinforcer frequency. Given a choice between obtaining food for an untimed response or for spaced responding, the former was preferred even though it markedly lowered potential reinforcer density. Similar results have been obtained with conjoint schedules involving reinforced pauses and a variety of accompanying schedules (see Zeiler & Solano N., 1982, for a review). An adequate theory of optimization would need to specify how the need to withhold responding operates against a reinforcer-maximization process.

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