

*RUN LENGTH, VISIT DURATION, AND REINFORCERS
PER VISIT IN CONCURRENT PERFORMANCE*

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The contingencies in each alternative of concurrent procedures consist of reinforcement for staying and reinforcement for switching. For the stay contingency, behavior directed at one alternative earns and obtains reinforcers. For the switch contingency, behavior directed at one alternative earns reinforcers but behavior directed at the other alternative obtains them. In Experiment 1, responses on the main lever, in S1, incremented stay and switch schedules and obtained a stay reinforcer when it became available. Responses on the switch lever changed S1 to S2 and obtained switch reinforcers when available. In S2, neither responses on the main lever nor on the switch lever were reinforced, but a switch response changed S2 to S1. Run lengths and visit durations were a function of the ratio of the scheduled probabilities of reinforcement (staying/switching). From run lengths and visit durations, traditional concurrent performance was synthesized, and that synthesized performance was consistent with the generalized matching law. Experiment 2 replicated and extended this analysis to concurrent variable-interval schedules. The synthesized results challenge any theory of matching that requires a comparison among the alternatives.

Key words: generalized matching law, scheduled reinforcer probability, scheduled reinforcer rate, run length, visit duration, lever press, rats

Studies of choice using concurrent operants frequently use two responses, each associated with a variable-interval (VI) schedule of reinforcement. The typical result is that the allocation of behavior (responses or time spent responding to one alternative) is proportional to the allocation of reinforcers (Herrnstein, 1961; Heyman, 1979). Baum (1974) extended this relationship as the generalized matching law, which can be expressed as

$$\log(B_1/B_2) = a \log(R_1/R_2) + \log b, \quad (1)$$

where B_1 and B_2 represent the numbers of Responses 1 and 2 or the times spent at Alternatives 1 and 2, R_1 and R_2 represent the numbers of reinforcers for B_1 and B_2 , a is a constant interpreted as an index of the sensitivity of behavior to different reinforcer allocations, and $\log b$ is a constant interpreted as a measure of the bias towards one alternative (Baum, 1974). Equation 1 plots as a straight line with slope a and intercept $\log b$. Matching also can be obtained with concur-

rent variable-ratio (VR) schedules, in a procedure some call synthetic VI schedules (Green, Rachlin, & Hanson, 1983), in which responses in each alternative advance the ratio counters in both alternatives (MacDonall, 1988).

Several different accounts of the generalized matching law have been proposed, and support can be found for each of them. A new approach using largely overlooked independent and dependent variables may be useful for developing a comprehensive account. The following shows that the generalized matching law can be expressed using two independent variables, stay and switch reinforcement, and two dependent variables, run length and visit duration. These modifications suggest a means of synthesizing performance and seeing whether the results are consistent with the generalized matching law. Because most investigations of choice use concurrent VI schedules, the following analysis will use concurrent VI as examples, but the conclusions also apply to concurrent VR procedures as programmed by MacDonall (1988).

Stay and Switch Schedules

Houston and McNamara (1981) developed a model to predict distributions of time on the alternatives that would maximize overall reinforcement rate on concurrent VI VI pro-

I thank Dagmar Hemmerich, Henry Marcucella, and Stacey Zaremba for many helpful comments on earlier versions of this manuscript, Liz Didie, Eric Frasier, Carl Falcone and Meg Ruggiero for assistance in data collection, and Jonathan Galente for technical assistance.

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cedures. In so doing they pointed out that the typical concurrent VI VI can be considered to consist of two pairs of schedules. Only one pair is operating at a time; as the organism moves between alternatives, the pair of schedules operating changes. One schedule in each pair reinforces responses on the current alternative and is the *stay* schedule. The second schedule in each pair reinforces the switch to the other alternative, thereby allowing the subject to obtain reinforcers set up for switching, and is the *switch* schedule. According to the distinction between earned and obtained reinforcers (Rachlin, Green, & Tormey, 1988), on the stay schedule reinforcers are earned and obtained by responses on the current alternative, whereas on the switch schedule, reinforcers are earned by responses on the current alternative but are obtained following switching. The interval length of the stay schedule of one pair of schedules is equal to the interval length of the switch schedule of the other pair. Thus, concurrent procedures consist of symmetrical pairs of schedules. Because only two timers are used to schedule reinforcers, each timer is used alternately to schedule stay and then switch reinforcers. That is, one timer functions as the stay schedule as the other timer functions as the switch schedule. Changing alternatives exchanges the stay and switch functions of each timer. For example, if Schedule 1 is VI 60 s and Schedule 2 is VI 120 s, then one pair consists of a VI 60 s for staying on Response 1 and a VI 120 s for switching to Response 2. As Response 1 occurs, the VI 60 s operates, and when reinforcement is available the next Response 1 is reinforced; the VI 120 s operates simultaneously with the VI 60 s, but when reinforcement is available, it is held until Response 2 occurs. Similarly, as Response 2 occurs, the VI 120 s operates, and when reinforcement is available the next Response 2 is reinforced; the VI 60 s operates simultaneously with the VI 120 s, and when reinforcement is available it is held until Response 1 occurs. If a changeover delay (COD) is used, then the switch reinforcer is collected by the first response after the COD elapses (Houston & McNamara, 1981).

Run Length and Visit Duration

Houston and McNamara (1981) pointed out (see also Skinner, 1950) that reinforce-

ment for staying and switching may establish a pattern of responding. That is, organisms may learn to switch after a certain number of responses on the present alternative. Run length, the number of responses before a switch, would be a function of the scheduled probabilities of reinforcement for staying and switching. Alternatively, organisms may learn to switch after a certain duration on an alternative. In this case, visit duration would be a function of the scheduled probabilities of reinforcement for staying and for switching.

Shimp (1982), using pigeons, showed that reinforcing switching to Key 2 only after a specific run length on Key 1 controlled the run length on Key 1. When two different run lengths were reinforced, the relative frequency of run lengths was a function of the relative frequency of reinforcement for those run lengths. Although these results reveal the influence of reinforcement for switching on run length, the joint effects of reinforcement for staying and switching were not examined.

Mechner (1958) showed that run length was sensitive to variations in the scheduled probability of reinforcement for staying and switching. A fixed-ratio schedule was associated with one lever, the counting lever. After responding on the counting lever had set up the reinforcer according to the fixed-ratio schedule, either a response on the counting lever or a response on a second lever collected the reinforcer. Mechner varied the scheduled probability of reinforcement for responses on the counting lever or the second lever and found that mean run length was directly related to the relative scheduled probability of reinforcement for a response on the counting lever as opposed to the second lever. This procedure can be viewed as similar to one pair of schedules in a concurrent procedure: Reinforcers delivered for responses on the counting lever are stay reinforcers, and reinforcers delivered for responses on the second lever are switch reinforcers. Viewed in these terms, Mechner (1958) provided data supporting the view that animals may learn to emit specific run lengths, depending on the relative scheduled probabilities of reinforcement for staying and switching.

Baum (1982) and Boelens and Kop (1983) extended the analysis of run length and visit duration to concurrent schedules. They

showed, on concurrent VI VI schedules, that run length and visit duration in one alternative increased as the relative probability of reinforcement for responding in that alternative increased. The analysis by Houston and McNamara (1981), that concurrent VI VI procedures consist of two pairs of schedules that each reinforce staying and switching, and the results reported by Baum (1982) and Boelens and Kop (1983) suggest that run length and visit duration are important behavioral measures in concurrent choice procedures.

Generalized Matching Law

The generalized matching law can be expressed in terms of run length or visit duration. When fitting Equation 1 to response and obtained reinforcer allocations, the total numbers of responses on the alternatives are the numerator and denominator of the left side of Equation 1. The frequency of changing to one alternative, C_n , must be within one of the frequency of changing to the other alternative. As long as the frequency of changing to each alternative is large (say, greater than 100), then dividing the numerator and denominator of the left side of Equation 1 by the frequency of changing to the other alternative is equivalent to dividing by a constant. Considering this, Equation 1 can be rewritten as

$$\begin{aligned} & \log[(B_1/C_2)/(B_2/C_1)] \\ & = a \log(R_1/R_2) + \log b. \end{aligned} \quad (2)$$

Just as behavior can be viewed on a per-visit basis, reinforcers can be as well. Dividing the numerator and denominator of the right side of Equation 2 by the frequency of changing to the other alternative yields

$$\begin{aligned} & \log[(B_1/C_2)/(B_2/C_1)] \\ & = a \log[(R_1/C_2)/(R_2/C_1)] + \log b. \end{aligned} \quad (3)$$

Because the changeover response ends the run, the number of responses and reinforcers in Alternative 1 are divided by the number of changes from Alternative 1 to Alternative 2, which is C_2 . Similarly, the number of responses and reinforcers in Alternative 2 are divided by the frequency of changes from Alternative 2 to Alternative 1, which is C_1 .

The number of reinforcers per visit on

each alternative is the sum of the reinforcers obtained from staying per visit on that alternative and from switching per visit to that alternative. The reinforcers per visit for staying on an alternative is the number of reinforcers for staying (Rt_n) divided by the number of visits, which is the number of switches to the other alternative, that is, Rt_1/C_2 and Rt_2/C_1 . The reinforcers per visit for switching to that alternative is the number of reinforcers for switching (Rw_n) divided by the number of switches to that alternative, that is, Rw_1/C_1 and Rw_2/C_2 . The number of reinforcers per visit, R_1/C_2 and R_2/C_1 , equal $Rt_1/C_2 + Rw_1/C_1$ and $Rt_2/C_1 + Rw_2/C_2$, respectively. Substituting the per-visit number of reinforcers into Equation 3 yields

$$\begin{aligned} & \log[(B_1/C_2)/(B_2/C_1)] \\ & = a \log\{[(Rt_1/C_2) + (Rw_1/C_1)] \\ & \quad \div [(Rt_2/C_1) + (Rw_2/C_2)]\} + \log b. \end{aligned} \quad (4)$$

Equation 4 states that the log of the ratio of run lengths is proportional to the log of the ratio of the sum of the stay and switch reinforcers obtained on each visit plus a constant. The above analysis can also be conducted using visit duration with an analogous outcome. Equation 4 suggests that run length or visit duration could be the behavioral basis of the generalized matching law.

Synthesizing Concurrent Performance

If the analysis leading to Equation 4 is correct, then one should be able to synthesize concurrent performance. Synthesizing a performance is one way of demonstrating the appropriateness of the analysis and the variables used in the analysis. For example, Shimp (1967) synthesized performance on VI schedules by first exposing pigeons to an unpaced VI 1-min schedule. Then, in different conditions he reinforced pecks according to paced VI 1-min schedules. A paced VI schedule reinforces a response only after the VI interval elapses and when that response terminates an interresponse time (IRT) within a certain range. He also recorded the resulting distribution of IRTs. He then combined the different paced IRT distributions using a weighted average. The weight for each paced IRT distribution was the relative frequency of rein-

forcement for the IRT in the unpaced schedule. The synthetic IRT distributions closely resembled the actual IRT distributions of individual pigeons on the unpaced VI schedule. This result suggests that the pattern of reinforced IRTs determined responding on the VI schedules. Similarly, synthesizing concurrent performance from visit duration, run length, and stay and switch reinforcers per visit may demonstrate the appropriateness of the analysis and these variables.

The decomposition of concurrent procedures into two pairs of stay and switch schedules suggests a means of synthesizing concurrent performance. Behavior directed at one alternative operates only one pair of schedules, and behavior directed at the other alternative operates the other pair of schedules. It should be possible to synthesize concurrent performance by exposing organisms to a pair of stay and switch schedules and varying the parameters across conditions. After data collection is complete, data from conditions that consist of symmetrical pairs of schedules are combined. For example, one condition consisting of VR 40 for staying and VR 80 for switching and another condition consisting of VR 80 for staying and VR 40 for switching form symmetric pairs. There should be orderly changes in run length and visit duration as a function of the schedule parameters. In addition, Equation 4 should fit the data.

The purposes of these experiments were (a) to examine the effect on run length and visit duration of varying the scheduled probabilities of reinforcement for staying and switching and (b) to synthesize concurrent performance from the performance of rats exposed to symmetrical pairs of schedules. In Experiment 1, VR rather than VI schedules were used because with VR schedules the momentary probability of reinforcement for switching or staying is roughly constant between responses. In concurrent VI VI procedures the momentary probability of reinforcement for staying and switching is always changing.

EXPERIMENT 1 METHOD

Subjects

The subjects were 4 male albino Sprague-Dawley rats obtained from Hilltop Animal

Labs Inc. and maintained at 80% of their free-feeding weights. They were approximately 130 days old when the experiment began and were housed individually in a temperature-controlled colony room on a 14:10 hr light/dark cycle with free access to water.

Apparatus

Four operant conditioning chambers were used. Each was 20 cm wide and 20 cm high, one was 30 cm long, and three were 20 cm long. Each was located in a sound- and light-controlled enclosure. The food cup, 5 cm square, was centered horizontally on one wall (20 cm wide) and the lower edge was 1 cm above the floor. The centers of two response levers, 5 cm long and 1 cm high (Gerbrands, G6312), were located 5.5 cm from either side of the vertical center line of the food cup and 6.5 cm above the floor. A minimum force of approximately 0.3 N operated each lever. A 24-VDC stimulus light was centered approximately 6 cm above each lever. A Gerbrands feeder, located behind the food cup, dispensed 45-mg Noyes Formula A/1 rodent pellets. A houselight, mounted on the ceiling of the enclosure, operated during sessions. White noise provided by a Grason-Stadler white noise generator (Model 901B) was presented through a speaker centered on the ceiling of the chamber. Located in an adjacent room was an IBM-compatible computer with hardware (MED Associates) and software (MED-PC®), which controlled contingencies and recorded responses.

Procedure

During S1 (noise on for Rats 223 and 225; noise off for Rats 224 and 226), responses on the main lever incremented the stay and switch VR counters. When the stay counter set up a reinforcer, it was delivered immediately. When the switch counter set up a reinforcer, it was delivered for the first press on the switch lever. Additional presses on the main lever before the switch reinforcer was obtained continued to increment the stay counter and deliver a stay reinforcer if one set up. The next value for the switch ratio was not incremented until the switch reinforcer was collected. Presses on the switch lever changed S1 to S2 (noise on or off; opposite to S1) and collected the reinforcer if one was set up. During S2, presses on the main lever

Table 1

Parameters of the stay and switch VR schedules and the number of sessions in each condition, the five-session sums of main-lever responses in S1 and S2, reinforcers obtained from each schedule, time in S1 and S2, and switches to S2 and S1.

Rat	Order	Reinforcement schedule		Sessions	Main-lever responses in		Reinforcers		Time (min) in		Switches to	
		Stay	Switch		S1	S2	Stay in S1	Switch to S2	S1	S2	S2	S1
223	1	40	40	30	10,595	706	265	235	192.7	61.3	1,413	1,416
	2	40	80	18	13,693	1,542	333	167	234.6	77.0	1,590	1,592
	3	40	160	16	16,395	656	411	89	206.7	60.8	669	669
	4	40	40	37	11,358	220	275	225	125.8	40.9	767	767
	5	80	40	17	14,889	413	182	318	154.2	56.8	1,238	1,240
	6	160	40	12	17,658	215	113	387	175.3	67.5	1,769	1,773
	7	40	40	11	11,128	412	272	228	108.3	38.6	852	853
	8	20	160	11	8,795	111	448	52	104.0	11.6	224	219
	9	160	20	10	11,678	132	69	431	118.4	72.4	1,078	1,078
	10	40	40	11	11,306	235	280	220	131.3	41.1	614	617
224	1	40	40	15	10,459	359	255	245	281.4	67.0	1,749	1,750
	2	40	20	12	7,510	137	176	324	198.3	43.9	1,131	1,134
	3	40	80	22	14,053	242	344	156	161.5	20.4	594	596
	4	40	160	14	16,576	139	413	87	180.1	18.3	556	556
	5	40	40	39	11,629	31	289	211	124.4	18.3	503	506
	6	80	40	11	15,589	65	193	307	168.1	31.1	852	850
	7	160	40	12	18,000	88	120	380	228.4	47.3	1,497	1,495
	8	40	40	13	11,237	52	278	222	129.5	22.1	635	638
	9	20	160	11	9,259	23	460	40	114.7	7.1	241	242
	10	160	20	12	11,354	6	72	428	177.7	43.6	991	995
	11	40	40	12	10,971	19	275	225	169.5	33.6	680	683
225	1	40	40	18	10,567	141	257	243	232.1	44.8	2,627	2,630
	2	40	20	12	7,133	61	168	332	163.0	36.0	2,092	2,093
	3	40	80	15	13,252	140	337	163	236.9	43.1	1,836	1,839
	4	40	160	21	16,163	85	409	91	238.1	20.7	1,317	1,317
	5	40	40	26	10,646	24	261	239	170.6	26.5	1,431	1,432
	6	80	40	13	9,504	33	110	209	230.8	104.9	1,602	1,605
	7	80	20	11	9,042	39	106	394	186.7	56.2	2,104	2,109
	8	20	80	20	8,200	4	411	89	159.1	12.0	484	486
226	1	40	40	37	10,118	680	257	243	133.7	44.0	2,647	2,651
	2	40	80	26	13,775	251	341	159	136.3	42.6	2,126	2,127
	3	40	160	18	16,269	254	408	92	146.8	18.4	1,185	1,185
	4	40	40	20	10,566	133	257	243	91.2	29.7	1,969	1,971
	5	80	40	13	13,566	64	155	313	232.2	79.0	3,689	3,686
	6	160	40	12	13,252	171	75	313	505.5	151.0	5,899	5,896
	7	40	40	11	10,309	164	264	236	114.0	32.0	1,818	1,821

had no effect, no counters incremented, and no reinforcers were delivered; a press on the switch lever changed S2 to S1 and was never reinforced.

In effect, for Rats 223 and 225 responses were occasionally reinforced for staying in noise on and for switching to noise off. However, in noise off, responses were never immediately reinforced for staying in noise off or for switching to noise on. For Rats 224 and 226, the stimulus conditions were reversed: Responses were occasionally reinforced for

staying in noise off and for switching to noise on.

Table 1 lists, for each rat, the sequence of conditions, and the number of sessions that each condition was in effect. There was no COD. The 20 ratios in each VR schedule were exponentially distributed and obtained by the method of Fleshler and Hoffman (1962), in which responses were treated as seconds. Ratios were rounded to the nearest whole number. Values from the set were randomly selected without replacement. Each day

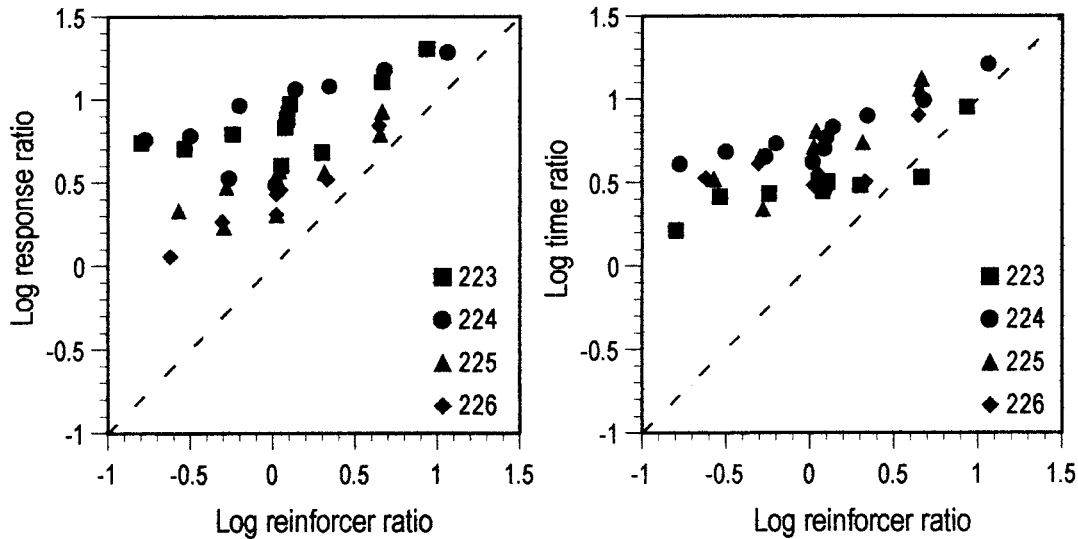


Fig. 1. Experiment 1 viewed as a two-lever concurrent procedure; the log ratio of responses and of time as a function of the log ratio of reinforcers (main lever/switch lever).

random selection began at a different position on the list. A condition remained in effect for at least 10 sessions and until visual inspection showed there were no apparent upward or downward trends in the proportional distribution of reinforcers, responses, and time for five consecutive sessions. The houselight was on only during sessions. Sessions were typically conducted 6 days a week and ended after 100 reinforcers.

Initial training. Rats were trained to approach the food cup at the sound of the food dispenser operating. Then pressing the main lever was shaped by the method of successive approximations. After approximately 40 reinforced presses on the main lever, VR schedules for staying and switching began, starting with VR 2. Ratio parameters increased by one or two when response rates reached about 15 to 25 responses per minute until VR 8 was reached. Then ratio parameters increased by about 25% when response rates were above 40 responses per minute. After about 15 to 20 sessions, the ratio values reached those used in the first condition. Pressing the switch lever was not shaped. This response emerged as the VR schedule for staying increased, producing less frequent reinforcement for responses on the main lever.

RESULTS

All results are based on the sum of the last 5 days' performance during each condition.

Table 1 presents the sums for frequency of main-lever responses in S1 and S2, reinforcers obtained from each schedule, time spent in S1 and S2, and switches to S2 and S1.

Because responses on the main lever and the switch lever were reinforced, the procedure can be analyzed as a two-lever concurrent schedule. Figure 1 shows that log response and time allocations are roughly linearly related to the log reinforcer allocation. The fits of Equation 1 to these data are presented in Table 2. The fits for individual rats were poor to excellent (r^2 ranging from .30 to .93), with moderate to small standard errors of estimate; the fits for the pooled data were poor ($r^2 = .35$ and .48), although standard errors of estimate were small. For all rats and the pooled data, there is considerable undermatching (a less than 1.0) and a large bias towards the main lever. This bias probably reflects the contingency that only presses on the main lever incremented the ratio schedules.

A response run began with the first response on the main lever after a switch and ended with a response on the switch lever. Mean run length was the number of responses on the main lever in an alternative divided by the number switches out of that alternative. A visit began when a rat switched into an alternative and ended with a press on the switch lever. Mean visit duration was the

Table 2

From Experiment 1, the slope (a), intercept ($\log b$), standard errors of estimate, and r^2 from the least squares fits of Equation 1 (two-lever concurrent analysis) and Equation 4 (synthesized concurrent analysis).

Rat	Responses					Time					df
	a	SE	$\log b$	SE	r^2	a	SE	$\log b$	SE	r^2	
Two-lever analysis											
223	0.303	0.102	0.841	0.050	.526	0.306	0.065	0.477	0.032	.736	8
224	0.349	0.113	0.886	0.056	.514	0.321	0.050	0.773	0.025	.823	9
225	0.463	0.109	0.493	0.047	.750	0.509	0.108	0.711	0.046	.787	6
226	0.576	0.070	0.400	0.027	.931	0.201	0.135	0.577	0.051	.306	5
Pooled	0.397	0.093	0.691	0.043	.350	0.338	0.061	0.640	0.028	.476	34
Synthesized concurrent analysis											
223	0.984	0.139	0.305	0.078	.962	0.805	0.099	0.075	0.056	.971	2
224	1.003	0.241	0.340	0.146	.896	0.601	0.137	0.111	0.083	.906	2
225	1.304	0.103	0.267	0.042	.994	1.065	0.437	0.200	0.180	.856	1
226	1.443	0.138	0.168	0.057	.991	0.180	0.415	0.037	0.172	.159	1
Pooled	1.033	0.137	0.241	0.071	.826	0.688	0.120	0.111	0.062	.733	12

time in S1 divided by the number of switches to S2. Figure 2 shows, on log-log coordinates, the mean run length and the mean visit duration in S1 as a function of the ratio of the scheduled probabilities of reinforcement (the scheduled probability of reinforcement for staying divided by the scheduled probability of reinforcement for switching). The scheduled probability of reinforcement for staying or switching was the inverse of the mean scheduled VR parameter ($1/VR$). Run length and visit duration increased as the ratio of the scheduled probabilities of reinforcement increased. Because responding in S2 was never reinforced and those run lengths never exceeded one, they are not shown.

Figure 2 also shows the rates of pressing the switch lever as a function of the ratio of scheduled probabilities of reinforcement. Rate of switching was the total number of presses of the switch lever divided by total session time. For 3 rats, rate of switching decreased as a function of the ratio of scheduled reinforcement probabilities. When the ratio of the scheduled probabilities of reinforcement was low, the rate of switching was high.

Equation 4 expresses the generalized matching law as the ratio of run lengths, or visit durations, as a function of the ratio of the sums of the per-visit frequencies of reinforcement for staying on one alternative and switching to that alternative. Performance on

concurrent schedules was synthesized by fitting Equation 4 to the run lengths, visit durations, and frequencies of reinforcement for staying and switching obtained from symmetrical pairs of schedules. For example, consider Conditions 2 and 5 for Rat 223. The schedules in Condition 2 consisted of VR 40 for staying and VR 80 for switching. The schedules in Condition 5 consisted of VR 80 for staying and VR 40 for switching. Combining these symmetric pairs into one procedure produces the equivalent of concurrent VR 40 VR 80, with responses at either alternative advancing counters for both alternatives (cf. Green et al., 1983; MacDonall, 1988).

The synthetic performance was calculated according to Equation 4, from the run lengths or visit durations shown in Figure 2 and the reinforcers per run calculated analogously from Table 1. Again assuming the parameters for Rat 223 in Conditions 2 and 5, the synthetic performance was a run in Alternative A (VR 80 stay and VR 40 switch) terminated by a response on the switch lever, and then a run in Alternative B (VR 40 stay and VR 80 switch) terminated by a response on the switch lever and returning to Alternative A. Because Conditions 2 and 5 produced different numbers of switches, run lengths and visit durations (rather than total responses and time) were used in calculating response and time ratios. The response ratio was the run length in Alternative A divided by the run length in Alternative B. Consulting

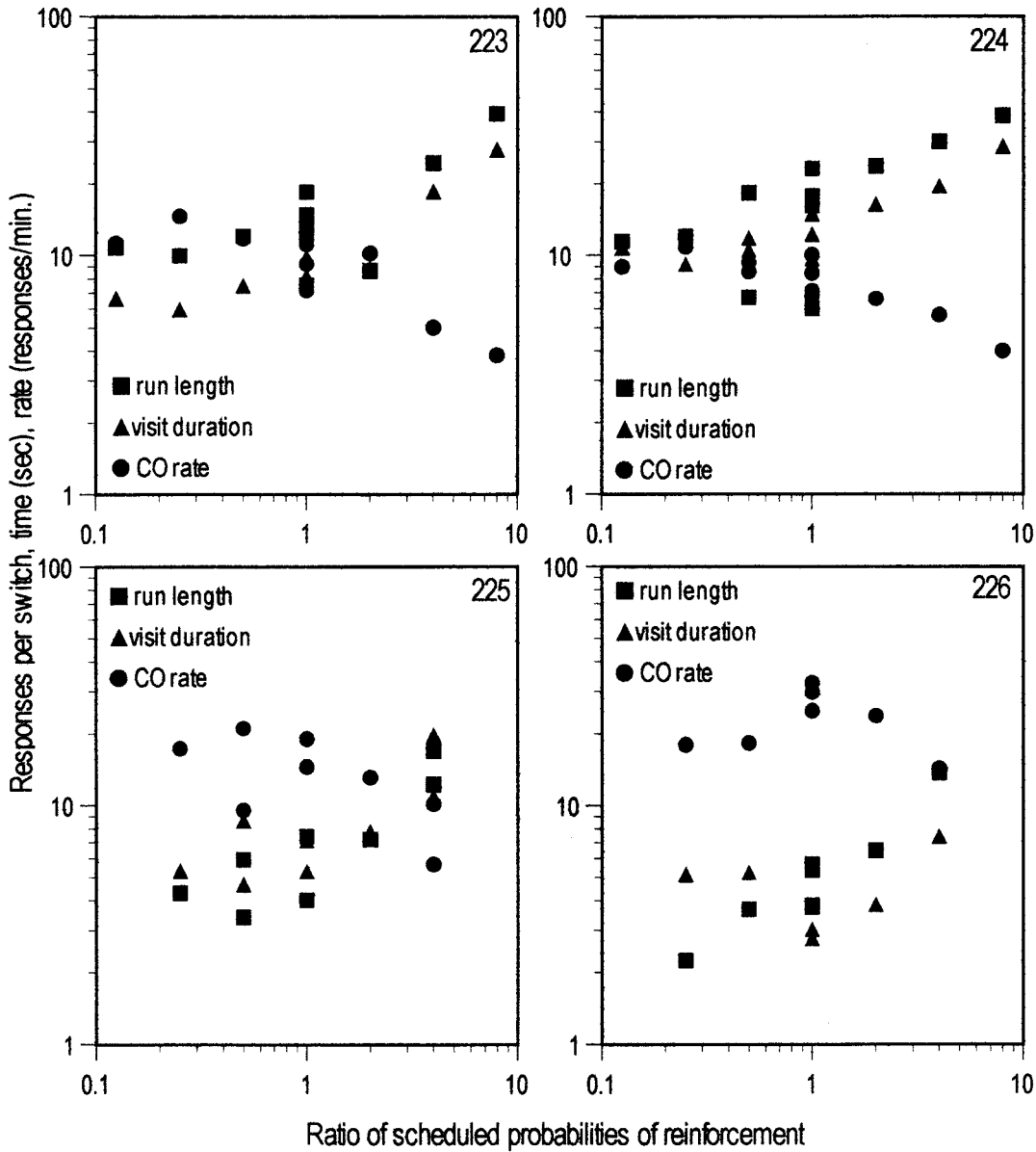


Fig. 2. From Experiment 1, on log-log coordinates, run length, visit duration, and rate of pressing the switch lever as a function of ratio of the scheduled probabilities of reinforcement for staying and switching ($1/VR$ stay)/($1/VR$ switch).

Table 1, we see that run length in Alternative A was 13,693 main-lever responses in Alternative A divided by 1,590 switches to Alternative B; run length in Alternative B was 14,889 main-lever responses in Alternative B divided by 1,238 switches to Alternative A. The time ratio was the ratio of the visit durations and was calculated analogously to response ratio.

Reinforcement ratios were also calculated from the mean reinforcers per run (rather than total reinforcers). Reinforcers for staying per run was the total number of reinforcers for staying divided by the number of switches out of that alternative; total reinforcers for switching per run was the total number of reinforcers for switching to that alternative divided by the total number of switches

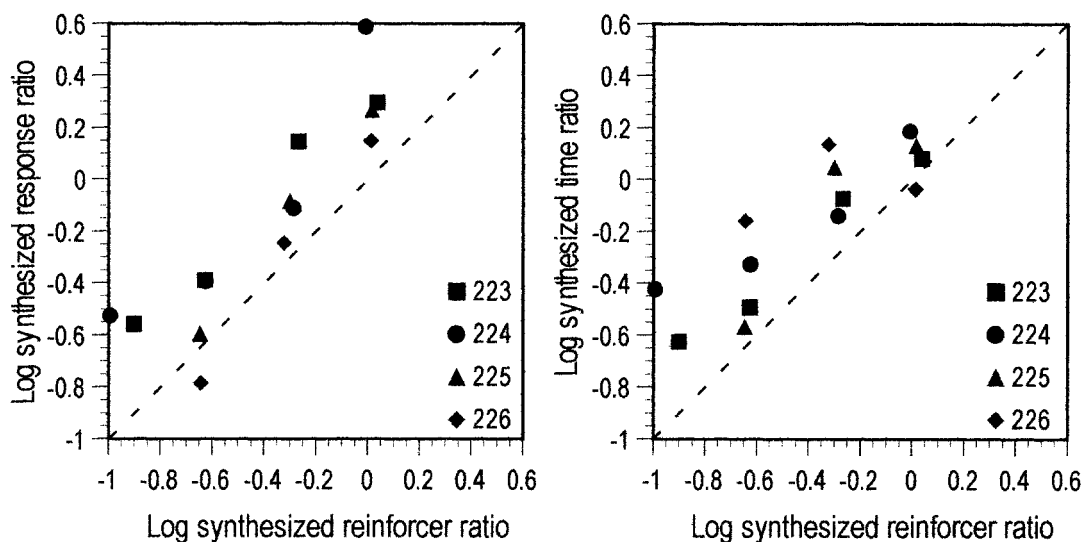


Fig. 3. From Experiment 1, the log of the synthesized response and time ratios as a function of the log of the synthesized reinforcer ratio. Concurrent performance was synthesized by combining run lengths, visit durations, and reinforcers per visit from symmetric schedule pairs that, if run at the same time, would have been equivalent to one-lever concurrent procedures. For example, data from the condition consisting of VR x for staying and VR y for switching was combined with data from the condition VR y for staying and VR x for switching.

to that alternative. For example, the mean reinforcers per run in Alternative A was the 182 stay reinforcers from Alternative A divided by 1,238 switches to Alternative B, plus the 167 reinforcers for switching to Alternative A divided by 1,592 switches to A. Similarly, the mean reinforcers per run in Alternative B was the 333 stay reinforcers from Alternative B divided by 1,590 switches to Alternative A, plus the 318 reinforcers for switching to Alternative B divided by 1,240 switches to B. The reinforcement ratio was the ratio of these two sums.

The denominator of the ratios always consisted of the data from the first of the two conditions that comprised the symmetric pair. Because there were more switches on the first exposure to VR 40 for staying and VR 40 for switching than on repetitions of that condition, only the last two replications were used to calculate synthetic performance. These rules, when applied to the data for Rat 223, produced Conditions 5, 6, 9, and 10 as the numerators and Conditions 2, 3, 7, and 8 as the respective denominators.

Figure 3 shows that log synthesized response allocations are roughly linearly related to log synthesized reinforcer allocations. Table 2 presents the fits of Equation 4 to indi-

vidual and pooled data. The individual fits were very good ($r^2 > .90$), and the pooled fit was good ($r^2 = .83$). Slopes ranged from 0.98 to 1.44, with large to moderate standard errors of estimate of slope. A bias for all rats was apparent despite the large standard error of estimate for bias.

Figure 3 also shows that log synthesized time allocations were roughly linearly related to log synthesized reinforcer allocations for 3 rats; there appears to be no systematic relation for Rat 226. Table 2 presents fits of Equation 4 to individual and pooled data. For 3 rats the fits were good ($r^2 > .85$), and the pooled fit was fair ($r^2 = .73$). Slopes ranged from 0.60 to 1.06, with large to moderate standard errors of slope. There was no reliable bias because of the large standard errors of bias.

Table 3 presents, for each condition, the obtained mean number of responses per reinforcer for each rat as a percentage of the mean minimum number of responses per reinforcer. The minimum number of responses per reinforcer was the sum of the inverse of the scheduled probabilities of reinforcement (see Herrnstein, 1961). In 22 conditions the obtained responses per reinforcer were within 9.9% of the minimum, and in 12 condi-

Table 3

Molar maximizing predicts that rats will make the fewest responses per reinforcer on concurrent VR VR procedures. For each condition, the minimum number of responses per reinforcer and the obtained number of responses per reinforcer as a percentage of the minimum for each rat are given.

VR schedule		Main-lever responses per reinforcer				
Stay	Switch	Mini-	Obtained as a percentage of minimum			
		mum	223	224	225	226
20	80	16			102.5	
20	160	17.8	98.9	104.2		
40	20	13.3		112.7	107.0	
40	40	20	106.0	104.6	105.7	101.2
40	40	20	113.6	116.3	106.5	105.7
40	40	20	111.3	112.4		103.1
40	40	20	113.1	109.7		
40	80	23.7	102.7	105.4	99.4	103.3
40	160	32	102.5	103.6	101.0	101.7
80	20	16			113.0	
80	40	26.7	111.7	116.9	111.7	108.7
160	20	17.8	131.4	127.7		
160	40	32	110.4	112.5		106.7

tions the obtained responses per reinforcer were between 10% and 17% of the minimum. In only 2 of the 36 conditions were the obtained responses per reinforcer more than 25% of the minimum. The two exceptions were from the same condition, VR 160 for staying and VR 20 for switching.

Momentary maximizing predicts specific run lengths for each condition. Responses on the main lever increased the momentary probability of switch reinforcement, and switch-lever responses did not change the momentary probability of switch reinforcement. The momentary probability of reinforcement for each press of the main lever is estimated by the reciprocal of the VR for staying. When the stay VR was greater than the switch VR, the momentary probability of reinforcement for switching was always greater than that for staying. In this case, momentary maximizing predicts simple alternation, that is, one main-lever response and then a switch response. One main-lever response was required because only main-lever responses incremented the switch schedules. When the stay VR was equal to or less than the switch VR, the momentary probability of reinforcement for switching starts out as less than the momentary probability of reinforcement for staying

Table 4

The run length predicted by momentary maximizing for the various schedule combinations used in Experiment 1 and the obtained mean run length for each rat.

Stay sched-ule	Switch sched-ule	Pre-dicted	Run length			
			Obtained			
			223	224	225	226
160	20	1	10.8	11.5		
80	20	1			4.3	
160	40	1	10.0	12.0		2.2
80	40	1	12.0	18.3	5.9	3.7
40	20	1			3.4	
40	40	2	13.4	15.7	5.7	5.0
40	80	3	8.6	23.7	7.2	6.5
40	160	5	24.5	29.8		13.7
20	80	5			16.9	
20	160	9	39.3	38.4		

and increases as the main lever is pressed. The momentary probability of reinforcement for switching is approximately $1 - [1 - (1/VR)]^N$, where N represents the number of main-lever responses since the last switch-lever response, that is, the run length. This expression says that the momentary probability of reinforcement for switching starts as the inverse of the switch schedule value. It increases as the run length increases, until a response on the switch lever, at which point the probability returns to the inverse of the switch schedule value. Table 4 shows the run lengths predicted by momentary maximizing and the obtained run lengths. As the predicted run lengths increased, the obtained run lengths increased. However, the obtained run lengths were much longer than predicted.

DISCUSSION

The results support the view that run length and visit duration are important for understanding performance on concurrent schedules. Run length, visit duration, and switching rate were a function of the scheduled probability of reinforcement for staying and switching (Figure 2). These changes in run length, visit duration, and switching rate correspond to those found by Baum (1982) and Boelens and Kop (1983) in concurrent VI VI procedures. The present results were adequately described as either a two-lever concurrent procedure (Figure 1) or a synthesized concurrent procedure (Figure 3). In

the synthetic analysis the slopes for responding were greater than typically found, and some slopes for time were less than typical (Baum, 1979; MacDonall, 1988; Wearden & Burgess, 1982).

Matching was obtained with concurrent procedures using VR instead of VI schedules, provided that responses on each alternative incremented a switch counter and reinforced switches to the other alternative (MacDonall, 1988). The synthetic procedure was equivalent to MacDonall's concurrent VR VR procedure, except that in the synthetic procedure switching was reinforced immediately after a switch response, whereas in MacDonall's procedure only responses on the main lever were reinforced. Although it was not the usual one-lever concurrent procedure, it seemed reasonable to consider the synthesis to produce a one-lever concurrent procedure (Findley, 1958) as programmed by MacDonall (1988).

EXPERIMENT 2

The purpose of Experiment 2 was to extend the results of Experiment 1 to concurrent VI VI schedules. Rats were exposed to only one pair of stay and switch schedules in a condition. Presses on one lever, the main lever, were occasionally reinforced according to the stay schedule. Presses on the switch lever were occasionally reinforced according to the switch schedule and did not change the stimuli. Across conditions, rats were exposed to all symmetric pairs of schedules.

METHOD

Subjects and Apparatus

The subjects were 4 male albino Sprague-Dawley rats obtained from Hilltop Animal Labs Inc. and maintained at 80% of their free-feeding weights. They were approximately 100 days old and experimentally naive when the present experiment began. They were housed individually in a temperature-controlled colony room on a 14:10 hr light/dark cycle with free access to water.

The apparatus was the same as used in Experiment 1.

Procedure

Throughout the sessions of each condition, the rats were exposed to one pair of VI sched-

ules. If both VI schedules operated throughout the session (except when reinforcers set up) and switching was reinforced immediately following the response on the switch lever, then the procedure would resemble a two-lever concurrent procedure. Instead, however, the switch timer stopped operating after a response on the switch lever and resumed operating only after the main lever was pressed. The stay schedule operated throughout the session except when a stay reinforcer set up. In this case, the stay timer stopped until a response on the main lever, which delivered the reinforcer. The switch timer stopped when a switch reinforcer set up. When a switch reinforcer set up, the next response on the switch lever delivered the reinforcer. Switch lever responses had no effect on the stimuli present, nor did they change the pair of schedules in effect.

To help simulate the alternatives of a one-lever concurrent procedure, both stimulus lights above the levers were on for the entire session during Conditions 1 through 3 for Rats 344 and 345 and Conditions 4 through 6 for Rats 346 and 347. The white noise was on for the entire session during Conditions 4 through 6 for Rats 344 and 345 and Conditions 1 through 3 for Rats 346 and 347. No COD was used. The 20 schedule values, exponentially distributed and obtained by the method of Fleshler and Hoffman (1962), were randomly selected from the set without replacement. Other details of the procedure were as in Experiment 1.

Initial training. After the rats were trained to approach the food cup at the sound of the food dispenser operating, responding on the main lever was shaped by the method of successive approximations. Responding on the switch lever was not shaped. It first occurred in the course of the first experimental condition, and stabilized before the condition was changed. Table 5 lists, for all rats, the sequence of conditions and the number of sessions in each condition.

RESULTS

All results are based on the sum of the last 5 days' performance in each condition. Table 5 presents these sums for number of responses on the main lever, number of switches (a press of the switch lever following a press of the main lever), number of presses

Table 5

In Experiment 2, for each rat, number of sessions in each condition, the VI schedules (in seconds) in each condition, number of main-lever responses, switches, additional presses on the switch lever, number of stay and switch reinforcers, and time on main lever and switch lever. Data are sums over the last five sessions of a condition. A switch occurred when the switch lever was pressed following a press on the main lever. Additional presses on the switch lever occurred when presses on the switch lever followed presses on the switch lever.

Rat	Order	Sessions	Schedules		Responses			Reinforcers		Time (min)	
			Stay VI	Switch VI	Main lever	Switches	Additional switch lever	Stay	Switch	Main lever	Switch lever
344	1	46	64	64	10,628	2,311	70	309	191	220.97	71.78
	2	21	43	128	8,818	1,225	16	396	104	236.96	38.28
	3	24	36	320	8,157	802	29	459	41	239.92	19.41
	4	10	64	64	8,840	1,723	513	303	197	236.79	71.46
	5	10	128	43	6,826	2,457	1,219	209	291	241.92	204.22
	6	10	320	36	9,266	3,997	3,425	103	334	228.39	326.60
345	1	46	64	64	13,833	4,023	151	349	151	188.90	114.06
	2	26	36	320	7,663	3,013	25	468	32	157.46	37.49
	3	14	43	128	10,750	3,872	112	426	74	180.14	59.19
	4	11	64	64	13,255	5,143	217	331	169	186.67	121.22
	5	11	320	36	16,145	8,689	390	124	376	232.02	331.92
	6	10	128	43	16,024	6,422	121	224	276	206.13	250.75
346	1	45	64	64	9,218	3,192	13	332	168	196.55	79.92
	2	25	43	128	9,132	2,462	9	412	88	201.24	45.21
	3	17	36	320	9,293	1,480	1	464	36	201.74	25.37
	4	10	64	64	10,478	3,471	1	312	188	207.55	72.33
	5	12	128	43	11,873	4,668	7	214	286	213.45	143.40
	6	13	320	36	12,981	6,764	103	120	357	221.31	230.28
347	1	46	64	64	5,778	2,159	3	344	156	182.16	131.06
	2	23	128	43	8,666	3,440	257	228	207	161.85	260.29
	3	18	320	36	11,656	6,252	87	168	332	209.88	599.94
	4	13	64	64	6,153	2,217	28	347	153	185.15	157.88
	5	10	43	128	5,987	1,407	8	422	78	193.41	80.43
	6	11	36	320	5,667	1,011	34	463	37	218.23	42.71

of the switch lever immediately following a switch, reinforcers obtained from each schedule, and time spent pressing the main lever and switch lever.

As with Experiment 1, this experiment can be analyzed as a two-lever concurrent procedure. Figure 4 presents log response ratio and the log time ratio (main lever/switch lever) as a function of the log reinforcer ratio (main lever/switch lever). For all rats the relations appear to be reasonably linear. Table 6 presents the fits of Equation 1 to these data. For time allocation, all fits were excellent; r^2 exceeded .97 and standard errors of estimate of slope and bias were small for each rat. Undermatching was found for each rat's time allocation; slopes ranged from 0.51 to 0.84, with a large bias for 3 of the rats. For these 3 rats, log response ratios were also well fitted by Equation 1; r^2 exceeded .93 and standard

errors of estimate of slope and bias were small. There was large undermatching for these rats, and a very large bias. However, for Rat 345, the fit of Equation 1 to response allocation was very poor; $r^2 = .36$, the slope approached zero, and the bias was large.

Figure 5 presents, on log-log coordinates, run length and visit duration as a function of the ratio of the scheduled rates of reinforcement—the scheduled rate of reinforcement for staying divided by scheduled rate of reinforcement for switching. The scheduled rate of reinforcement was the inverse of the programmed schedule value (1/VI). Mean run length was calculated by dividing the total presses on the main lever by the number of switches. Mean visit duration was the total session duration divided by the number of switches. For 3 rats, run length increased as the ratio of the scheduled rates of reinforce-

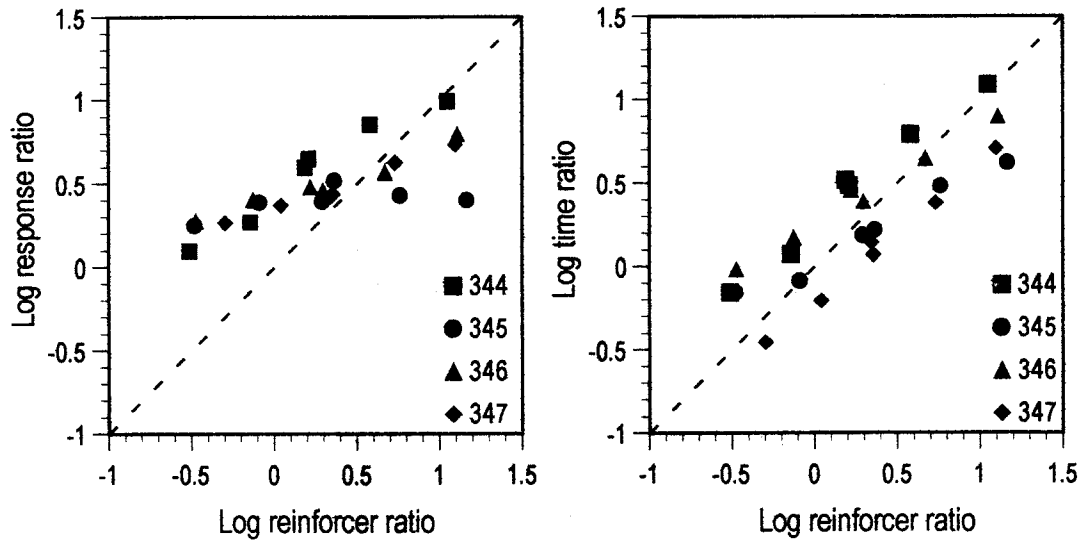


Fig. 4. Experiment 2 viewed as a two-lever concurrent procedure; the log ratio of responses and log ratio of time as a function of the log ratio of reinforcers (main lever/switch lever).

ment increased. For the same 3 rats, visit duration increased as the ratio of the scheduled rates of reinforcement increased. There were no systematic changes in the run length or visit duration for Rat 345.

Figure 5 also presents the rate of pressing the switch lever as a function of the ratio of the scheduled rates of reinforcement. The switch rate was the number of presses on the switch lever (switches plus additional presses on the switch lever) divided by total session

duration. The rate of pressing the switch lever rather than the rate of switching is presented because the rate of switching is the inverse of visit duration. Visit duration as a function of the ratio of the scheduled rates of reinforcement has already been presented. With the exception of Rat 345, the switch rate increased as the ratio of the scheduled rates of reinforcement increased.

Concurrent performance was synthesized from the visit durations, run lengths, and

Table 6

From Experiment 2, the slope (*a*), intercept (*log b*), standard errors of estimate, and *r*² from least squares fits to Equation 1 (two-lever analysis) using total responses, time, and reinforcers on the two levers; and to Equation 4 (synthetic concurrent analysis) using run lengths, visit durations, and reinforcement per visit for staying and switching.

Rat	Responses					Time				
	<i>a</i>	<i>SE</i>	<i>log b</i>	<i>SE</i>	<i>r</i> ²	<i>a</i>	<i>SE</i>	<i>log b</i>	<i>SE</i>	<i>r</i> ²
Two-lever analysis										
344	0.716	0.096	0.344	0.052	.933	0.829	0.059	0.279	0.032	.980
345	0.091	0.060	0.355	0.038	.361	0.514	0.042	0.040	0.026	.974
346	0.308	0.034	0.408	0.020	.951	0.580	0.033	0.261	0.019	.987
347	0.349	0.027	0.335	0.016	.977	0.837	0.036	-0.211	0.021	.993
Pooled	0.311	0.057	0.392	0.033	.577	0.634	0.086	0.110	0.051	.710
Synthesized concurrent analysis										
344	0.718	0.178	-0.018	0.105	.942	0.545	0.008	0.138	0.005	1.000
345	0.019	0.116	-0.094	0.068	.025	-0.114	0.158	-0.067	0.092	.342
346	0.601	0.073	-0.067	0.044	.985	0.374	0.080	-0.009	0.048	.956
347	0.510	0.036	-0.006	0.021	.995	0.301	0.040	-0.038	0.024	.983
Pooled	0.477	0.079	-0.008	0.046	.787	0.290	0.063	0.035	0.037	.677

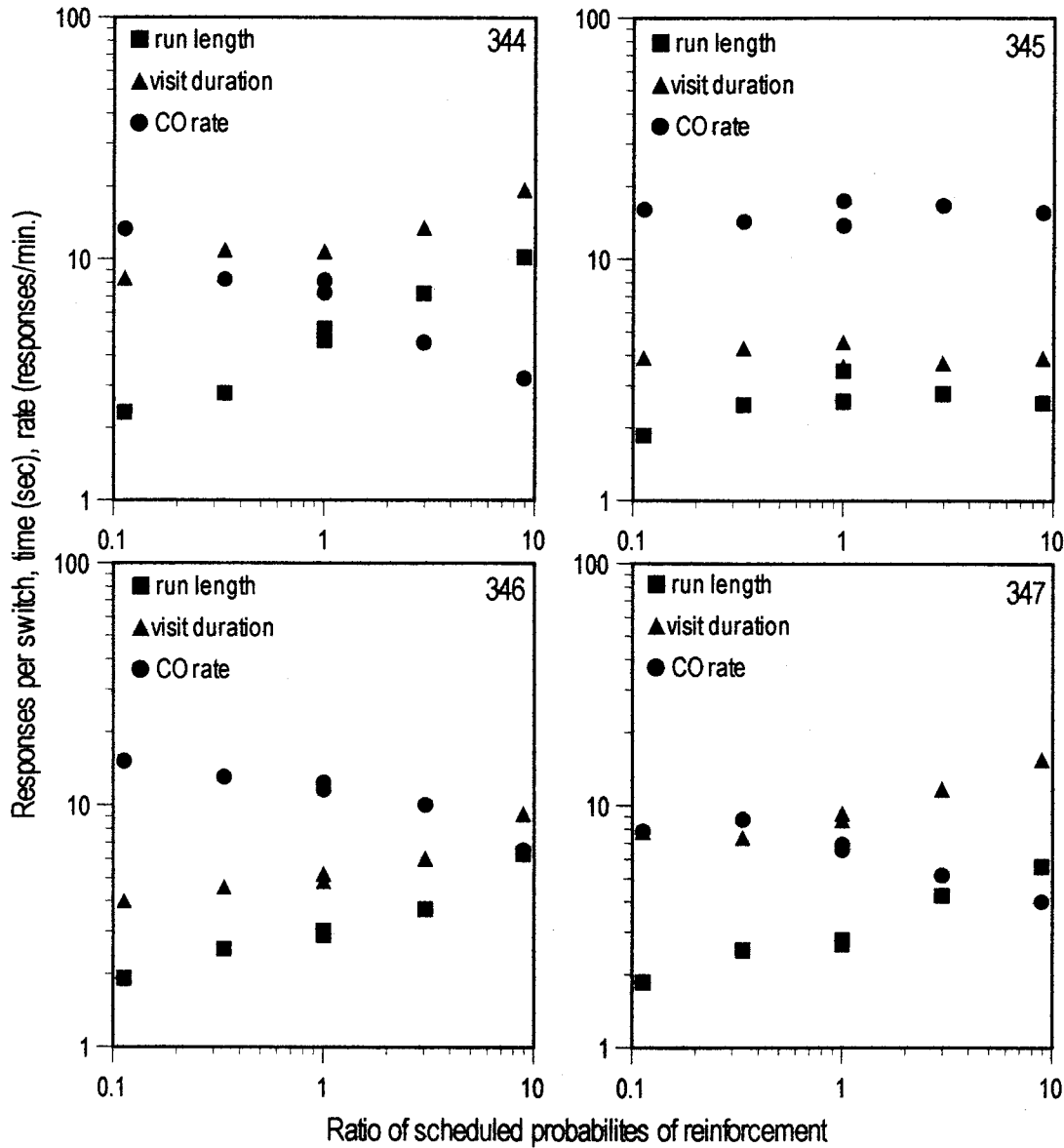


Fig. 5. From Experiment 2, on log-log coordinates, run length, visit duration, and rate of pressing the switch lever as a function of the ratio of the scheduled rates of reinforcement for staying and switching $(1/VI \text{ stay}) / (1/VI \text{ switch})$.

number of reinforcers per visit for staying and switching in a manner analogous to that in Experiment 1. The conditions that were combined were the symmetric pairs. For example, one symmetric pair was, for Rat 344, Condition 2, VI 43 s for staying and VI 128 s for switching, and Condition 5, VI 128 s for staying and VI 43 s for switching. All ratios were calculated by dividing data from the light condition by data from the noise con-

dition. Because the light was on during Condition 2 and noise was on during Condition 5, the per-visit data from Condition 2 were divided by the per-visit data from Condition 5. Figure 6 shows that, for 3 rats, log synthesized response and time allocation both increased as a roughly linear function of log synthesized reinforcer allocation.

Table 6 presents the fits of Equation 4 to the synthesized concurrent performance. For

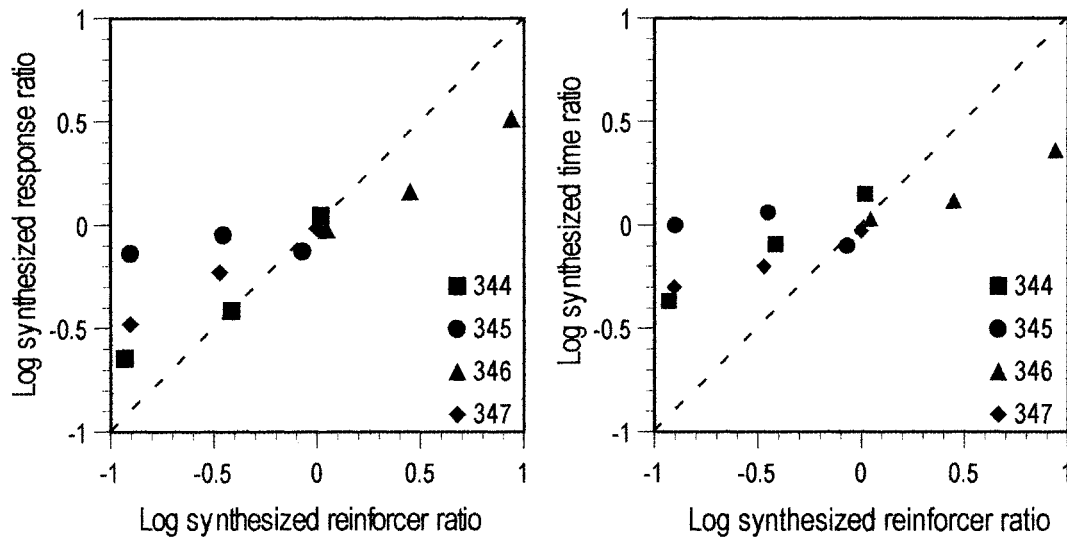


Fig. 6. From Experiment 2, the log of the synthesized response ratio as a function of the log of the synthesized reinforcer ratio, and the log of the synthesized time ratio as a function of the log of the synthesized reinforcer ratio. For Rats 344, 345, and 347 the scheduled rate of reinforcement for the stay schedules in noise was less than or equal to the scheduled rate of reinforcement for stay schedule in light. Consequently, the data points for these rats are to the left of zero. The opposite was the case for Rat 346; the data points for Rat 346 are to the right of zero.

3 rats, the synthesized time distributions were well fitted by Equation 4, with r^2 greater than .95 and small standard errors of estimate of slope and bias. The slopes were very low, and Rat 344's time allocation was biased towards the light. The slope of the fit for Rat 345 was near zero, as was expected from the invariant visit durations shown in Figure 5. The fits of response allocation for the same 3 rats were

Table 7

Molar maximizing predicts that behavior is distributed so that the maximum number of reinforcers is obtained. The obtained number of reinforcers (stay plus switch) as a percentage of the maximum possible to obtain are presented below. The maximum possible number of reinforcers was the total session duration divided by the stay VI schedule plus the total session duration divided by the switch VI schedule.

VI schedule		Obtained reinforcers as percentage of maximum			
Stay	Switch	344	345	346	347
320	36	41.8 ^a	46.9	55.9 ^a	32.8
128	43	59.5	57.9	74.2	54.7 ^a
64	64	88.2	87.5	95.1	81.1
43	128	96.3	110.3	107.4	96.9
36	320	102.2	135.5	116.5	101.7

^a 500 reinforcers were obtained except in these conditions (see Table 5 for the actual number of reinforcers obtained).

good ($r^2 > .94$), with small standard errors of estimate of slope and bias. Although these slopes are higher than each rat's slopes for time allocation, undermatching still occurred. There was no reliable bias. The fit for Rat 345 was poor, the slope was close to zero, and there was no reliable bias. Again, the near-zero slope reflects the consistent run lengths shown in Figure 5.

Table 7 presents the obtained mean number of reinforcers as a percentage of the mean maximum possible number of reinforcers. The maximum number of reinforcers was the sum of the session duration divided by the stay VI schedule, plus the session duration divided by the switch VI schedule. When the scheduled rate of reinforcement for staying was lowest and the scheduled rate of reinforcement for switching was highest, rats obtained fewer reinforcers than predicted; they obtained as little as 33% of the possible reinforcers. As the scheduled rates of reinforcement for staying increased and for switching decreased, the percentage of the mean maximum number of reinforcers actually obtained increased, until slightly more than the mean maximum number of reinforcers were obtained. Rat 345 obtained the greatest percentage of the maximum, at 135.5%. Presum-

ably, Rats 345 and 346 obtained more than the maximum possible due to random variations in sampling from the 20 stay and 20 switch intervals. In the condition that produced the largest deviation from the maximum possible number of reinforcers (VI 36 s for staying and VI 320 s for switching), 450 reinforcers were predicted to occur from the stay schedule and only 50 reinforcers from the switch schedule. Rats 345 and 346 obtained more stay reinforcers than expected and fewer switch reinforcers, supporting the view that variations in sampling resulted in more short VI intervals being selected for the stay schedule or more long intervals being selected for the switch schedule. This resulted in obtaining more than the theoretical maximum number of reinforcers.

DISCUSSION

The results from Experiment 2 replicate and extend the results from Experiment 1 to concurrent VI VI schedules. These data were adequately described as a two-lever concurrent procedure; the fits for 3 rats' behavior allocations by Equation 1 were good (Figure 4 and Table 6). Run lengths and visit durations were a function of the ratio of the scheduled reinforcement rates (Figure 5). These results are consistent with the view that run length and visit duration are the relevant measures for understanding performance on concurrent VI VI procedures, which are commonly used in research related to the generalized matching law. For both responses and time, Equation 4 fitted the synthesized concurrent performance of 3 of the 4 rats (Figure 6 and Table 6).

GENERAL DISCUSSION

The results of these experiments showed that run length and visit duration increased as the ratio of the scheduled probabilities (Experiment 1) and rates (Experiment 2) of reinforcement increased. In addition, in both experiments, behavior allocation was well described by the generalized matching law when the procedure was analyzed as either a two-lever concurrent procedure or a synthesized concurrent procedure.

The results of the synthesized concurrent analysis support the view that run lengths and visit durations are the relevant behavioral

measures in studies of concurrent choice. Changing the scheduled probability (Experiment 1) and rate (Experiment 2) of reinforcement for staying and switching changed the consequences for and thus the likelihood of staying on one alternative or switching to the other alternative (Figures 2 and 5). The changes in run length are consistent with the expectation that as relative likelihood of reinforcement for staying increases, run lengths increase, and as relative likelihood of reinforcement for switching increases, run lengths decrease.

Equation 4 fitted the synthesized concurrent performances well. MacDonall (1988), using VR schedules, reported slopes ranging from 0.45 to 0.91 for response and time allocation. In the synthesis, there was some overmatching as slopes in Experiment 1 ranged from 0.98 to 1.40 for response allocation and from 0.18 to 1.06 for time allocation. In Experiment 2, ignoring Rat 345, the slopes ranged from 0.51 to 0.72 for response allocation and from 0.30 to 0.54 for time allocation. Compared with slopes from procedures that do not immediately reinforce a switch response, the slopes from Experiment 2 are low (Baum, 1979; Wearden & Burgess, 1982). These low slopes may reflect the absence of a COD. Most researchers use a COD, and although slopes approximating 1.0 are reported without a COD (Baum, 1982; Heyman, 1979), often the use of a COD increases slope towards 1.0.

There was one major difference between the contingencies used in the present experiment and those used in concurrent schedules. In concurrent schedules, the reinforcement for switching into an alternative may include both the switch reinforcer and the delayed effects of stay reinforcers delivered during that visit. Unless the impact of these more delayed reinforcers on behavior allocation proves to be significant, the present results support the view that run lengths and visit durations are the relevant behavioral measures affected by the scheduled probabilities or rates of reinforcement for staying and switching.

These results are relevant to theories of matching. The synthesized performance was consistent with the generalized matching law despite rats' exposure to the two alternatives occurring on different days. If one assumes

that matching in the synthesized treatment occurs for the same reasons as matching under typical concurrent schedules, then these results could be viewed as challenging any theory of matching that requires comparisons between the two alternatives. Examples of such theories include: matching as a fundamental principle of behavior (Herrnstein, 1970), melioration (Vaughan, 1981), and scalar expectancy theory (SET; Gibbon, Church, Fairhurst, & Kacelnik, 1988).

One view of the generalized matching law is that it is a fundamental behavioral process used to understand other phenomena and not to be understood by other more fundamental processes (Herrnstein, 1970; Herrnstein & Heyman, 1979). Matching in the synthetic analyses was obtained from alternatives (conditions) that did not alternate, and were sometimes separated by other alternatives (conditions). Such matching is not easily interpreted as reflecting a fundamental behavioral process, because it was not possible to compare behavior and reinforcer allocations across alternatives that were presented on different days.

Melioration (Vaughan, 1981) proposes that organisms move to the alternative with the higher local rate of reinforcement. This produces equal local rates of reinforcement in the two alternatives of a concurrent procedure, which is another way of expressing the generalized matching law. The problem with melioration resembles that with the view that matching is fundamental. The synthesized matching reported here cannot be a straightforward result of melioration, because there is no possibility of comparing reinforcement rates and switching to the alternative with the higher rate of reinforcement.

Gibbon et al. (1988) used SET to analyze concurrent choice. They proposed that rats sample from memory the times to reinforcement and press the lever associated with the smallest time. SET, as presently conceived, does not apply to the synthetic results of Experiments 1 or 2. Because the alternatives were presented on different days, it is not possible for the rat to sample from two time or response distributions and to respond to the shortest expected time or fewest number of responses to reinforcement. A modification of SET may avoid the impossibility of rats' comparing expected times or responses

to reinforcement from different conditions in the present experiments. If SET has rats sample the times or responses to reinforcement from the stay and switch schedules, then SET might account for the synthesized results. But then in typical concurrent procedures, rats need to have four separate timers, one for each of the four schedules.

Molar maximizing, which does not propose that organisms make comparisons among the alternatives and does propose that animals distribute responses to obtain the maximum reinforcement rate (Green et al., 1983; Houston & McNamara, 1981; Rachlin, 1978), predicts some of the results of the present experiments. In Experiment 1, molar maximizing proposes that rats respond to obtain the minimum number of responses per reinforcer in S1. If molar maximizing occurs in each alternative, then molar maximizing could account for the synthesized performance. With two exceptions, rats responded within 17% of the predictions by molar maximizing (Table 3). These results are consistent with molar maximizing, indicating that molar maximizing could account for the synthesized results. In Experiment 2, molar maximizing accounts for the results of conditions in which the scheduled rate of reinforcement for staying is equal to or greater than the scheduled rate of reinforcement for switching. However, in eight conditions, all conditions in which the scheduled rate of reinforcement for staying was less than that for switching, rats obtained less than 75% of the maximum number of reinforcers. This result does not follow from a simple application of molar maximizing.

Momentary maximizing, which does not propose that organisms make comparisons among the alternatives and does propose that animals emit, at the moment, the response most likely to be reinforced (Shimp, 1966), accounts in a straightforward fashion for few of the present results. Because Experiment 1 used VR schedules based on Fleshler and Hoffman (1962), it was possible to estimate the run length predicted by momentary maximizing. The obtained run lengths were 2 to 15 times longer than those predicted by momentary maximizing (Table 4). That is, the rats did not press the switch lever when the momentary probability of reinforcement for switching was slightly greater than the momentary probability of reinforcement for stay-

ing. Rather, a switch occurred when the momentary probability of reinforcement for switching was much greater than the momentary probability of reinforcement for staying. The difference between the observed and predicted run lengths increased as the predicted run lengths decreased. MacDonall (1988) found similar results.

Three contingencies in the current procedure may have produced these longer-than-predicted runs. First, after a press on the main lever, the two response alternatives were not equivalent. Following a press on the main lever, another press on the main lever was easier than moving from the main lever to the switch lever and then pressing. Second, a switch-lever response did not increment reinforcement probability for any stay or switch schedule. Third, pressing the switch lever changed the alternative and schedules in effect to extinction, which meant that a return to the alternative in which responses were reinforced, and in which main-lever responses incremented reinforcement probability, required a second switch-lever response. Each of these factors might be expected to increase the run length. Although calculating the exact run lengths for each condition requires a more complicated model, the function in Figure 2 is consistent with momentary maximizing. That is, as the scheduled probability of reinforcement for switching decreased compared to the scheduled probability of reinforcement for staying, the run lengths increased. Because Experiment 2 used VI schedules, in which the passage of time drives the momentary probability of reinforcement, all the sequential IRTs must be known to calculate the precise visit durations predicted by momentary maximizing. IRTs were not recorded in the present experiments.

The present analysis is consistent with the results of probe tests of the transitivity of preference (Belke, 1992; Gibbon, 1995; Williams & Bell, 1996). Pigeons were exposed to two concurrent procedures in a multiple schedule (Belke, 1992). One component consisted of VI 20 s and VI 40 s on Keys 1 and 2, respectively. The second component consisted of VI 40 s and VI 80 s on Keys 3 and 4, respectively. After behavior allocation stabilized, Belke presented concurrent probes consisting of stimuli associated with the VI 40-s schedules on Keys 2 and 3, respectively. He

obtained what appeared to be a preference for the stimulus presented on Key 3 that was presented during training with the VI 80-s schedule on Key 4.

Williams and Bell (1996) replicated this finding and recorded response rates, obtained reinforcement rates, and run lengths in each alternative. They found that run length was the best predictor of the pigeons' preference during the probe trials. The run length during training trials was the run length during the probe trials. This suggests key color and position set the occasion for a specific run length, and run length varied accordingly as pigeons moved between different colored keys. Williams and Bell were unable to identify the variables that produced the different run lengths. The present research supports Williams and Bell's interpretation that run length was the critical factor in Belke's (1992) result, and suggests that the ratio of the scheduled rates of reinforcement for staying and switching was the variable that produced different run lengths during training.

Gibbon (1995) also replicated Belke's (1992) study and included an additional comparison during probe trials. He presented the stimulus associated with the VI 20 s on Key 1 and presented on Key 3 the stimulus associated with VI 40 s, which was presented during training with the VI 80 s on Key 4. He found a 2:1 preference for the stimulus associated with the VI 40-s schedule over the stimulus associated with the VI 20-s schedule. Gibbon's data support the view that it is the behavior during each alternative in training that is critical for determining choice during probes. The distribution of visit durations in each stimulus obtained during training was virtually identical to the distribution obtained from the same stimulus during probes. This finding supports the idea that stimulus control of run length and visit duration is relevant.

Finally, it is worth noting that the present analysis of concurrent performance is related to analyses based on changeover rate or changeover probability (e.g., Dreyfus, Dorman, Fetterman, & Stubbs, 1982; Heyman, 1979; Mark & Gallistel, 1994). In the present experiments, changeover rate was the inverse of the visit duration to one alternative. Consistent with the emphasis on changeover

probability, the results presented in Figures 2 and 5 show that visit durations from each alternative are a function of the ratio of the probabilities or rates of reinforcement.

REFERENCES

- Baum, W. M. (1974). On two types of deviations from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*, 22, 231-242.
- Baum, W. M. (1979). Matching, undermatching, and overmatching in studies of choice. *Journal of the Experimental Analysis of Behavior*, 32, 269-281.
- Baum, W. M. (1982). Choice, changeover, and travel. *Journal of the Experimental Analysis of Behavior*, 38, 35-49.
- Belke, T. W. (1992). Stimulus preference and the transitivity of choice. *Animal Learning & Behavior*, 20, 401-406.
- Boelens, H., & Kop, P. F. M. (1983). Concurrent schedules: Spatial separation of response alternatives. *Journal of the Experimental Analysis of Behavior*, 40, 35-45.
- Dreyfus, L. R., Dorman, L. G., Fetterman, J. G., & Stubbs, D. A. (1982). An invariant relation between changing over and reinforcement. *Journal of the Experimental Analysis of Behavior*, 38, 327-338.
- Findley, J. D. (1958). Preference and switching under concurrent scheduling. *Journal of the Experimental Analysis of Behavior*, 1, 123-144.
- 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. (1995). Dynamics of time matching: Arousal makes better seem worse. *Psychonomic Bulletin and Review*, 2, 208-215.
- Gibbon, J., Church, R. M., Fairhurst, S., & Kacelnik, A. (1988). Scalar expectancy theory and choice between delayed rewards. *Psychological Review*, 95, 102-114.
- Green, L., Rachlin, H., & Hanson, J. (1983). Matching and maximizing with concurrent ratio-interval schedules. *Journal of the Experimental Analysis of Behavior*, 40, 217-224.
- Herrnstein, R. J. (1961). Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior*, 4, 267-272.
- Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior*, 13, 243-266.
- Herrnstein, R. J., & Heyman, G. M. (1979). Is matching compatible with reinforcement maximization on concurrent variable interval, variable ratio? *Journal of the Experimental Analysis of Behavior*, 31, 209-223.
- Heyman, G. (1979). A Markov model description of changeover probabilities in concurrent variable-interval schedules. *Journal of the Experimental Analysis of Behavior*, 31, 41-51.
- Houston, A. I., & McNamara, J. (1981). How to maximize reward rate on two variable interval paradigms. *Journal of the Experimental Analysis of Behavior*, 35, 367-396.
- MacDonall, J. S. (1988). Concurrent variable-ratio schedules: Implications for the generalized matching law. *Journal of the Experimental Analysis of Behavior*, 50, 55-64.
- Mark, T. A., & Gallistel, C. R. (1994). Kinetics of matching. *Journal of Experimental Psychology: Animal Behavior Processes*, 20, 79-95.
- Mechner, F. (1958). Probability relations within response sequences under ratio reinforcement. *Journal of the Experimental Analysis of Behavior*, 1, 109-121.
- Rachlin, H. (1978). A molar theory of reinforcement schedules. *Journal of the Experimental Analysis of Behavior*, 30, 345-360.
- Rachlin, H., Green, L., & Tormey, B. (1988). Is there a decisive test between matching and maximizing? *Journal of the Experimental Analysis of Behavior*, 50, 113-123.
- Shimp, C. P. (1966). Probabilistically reinforced choice behavior in pigeons. *Journal of the Experimental Analysis of Behavior*, 9, 443-455.
- Shimp, C. P. (1967). The reinforcement of short inter-response times. *Journal of the Experimental Analysis of Behavior*, 10, 425-434.
- Shimp, C. P. (1982). Choice and behavioral patterning. *Journal of the Experimental Analysis of Behavior*, 37, 157-169.
- Skinner, B. F. (1950). Are theories of learning necessary? *Psychological Review*, 57, 193-216.
- Vaughan, W., Jr. (1981). Melioration, matching, and maximizing. *Journal of the Experimental Analysis of Behavior*, 36, 141-149.
- Wearden, J. H., & Burgess, I. S. (1982). Matching since Baum (1979). *Journal of the Experimental Analysis of Behavior*, 38, 339-348.
- Williams, B. A., & Bell, M. C. (1996). Changeover behavior and preference in concurrent schedules. *Journal of the Experimental Analysis of Behavior*, 65, 513-526.

Received February 21, 1997
Final acceptance January 6, 1998