

*STRICT AND RANDOM ALTERNATION IN CONCURRENT
VARIABLE-INTERVAL SCHEDULES*

DOUGLAS ELLIFFE AND MICHAEL DAVISON

THE UNIVERSITY OF AUCKLAND

Six pigeons responded on pairs of concurrent variable-interval schedules with, in different parts, four different arrangements of alternation between schedules. Following a single switching-key response, alternation was either strict or random, and the alternative presented after a switch (the postswitch alternative) was either signaled by the location of the switching key or unsignaled. Generalized-matching analyses showed little difference in behavior among the different alternation arrangements, except the usual finding of lower sensitivity of response allocation than time allocation was eliminated by arranging random alternation. Patterns of interchangeover times were similar for all arrangements except signaled random alternation. Differences in behavior preceding the different postswitch alternatives were found in the signaled random alternation procedure. Preference was biased towards the color of the signaled postswitch alternative and showed increased sensitivity when the postswitch alternative was to be the one with the higher reinforcer rate. Interchangeover times were substantially shorter when the postswitch alternative was signaled to be different from the current alternative than when it was signaled to be the same. However, when separate reinforcer ratios were calculated for the different postswitch alternatives, those effects were eliminated or greatly reduced. We suggest that, although behavior is indeed influenced by the postswitch alternative, the mechanism is indirect. That is, the distributions of reinforcers between alternatives obtained before each postswitch alternative differ when those alternatives are signaled, and those distributions are discriminated, but the same relations between choice and relative reinforcement hold irrespective of which postswitch alternative is signaled.

Key words: choice, concurrent schedules, generalized matching, interchangeover time, strict alternation, random alternation, key peck, pigeons

Concurrent schedules, particularly concurrent variable-interval (VI) schedules, have been widely used in the study of behavior allocation or choice. For two-alternative choice, two functionally equivalent procedures have been used: the switching-key procedure and the two-key procedure. In the switching-key concurrent schedule (Findley, 1958), responding to a switching key alternates the two reinforcement schedules and associated stimuli on the main key. In the two-key procedure (Herrnstein, 1961), each schedule is associated with a different response alternative (e.g., left or right), and changing between alternatives requires physical movement between the keys. Both of these procedures enforce a strict alternation of alternatives such that responding on one alternative is invari-

ably followed by exposure to the other alternative. Thus, when behavioral allocation is analyzed as a function of reinforcers received in each component using the generalized matching law (Equation 1), the analysis is completely confounded with the reinforcers obtained in the *following* component.

Do the conditions in the following alternative affect responding in the current alternative? We might hypothesize that subjects would stay a longer time and emit more responses in an alternative when the next alternative was lower in reinforcer rate, and stay a shorter time and emit fewer responses in a component when the signaled next component was a higher reinforcer rate. Research on multiple VI VI schedules (Williams, 1979, 1981; Wilton & Gay, 1969) suggests that this might occur. When multiple-schedule components do not alternate simply, response rates in components that are regularly followed by lower reinforcer-rate components are higher than in components followed by higher rate components. This effect, called the *following-component effect* by Williams, is an example of anticipatory contrast. If this is also true in concurrent schedules, behavior allo-

We thank the staff and graduate students of the Experimental Analysis of Behaviour Research Unit who helped conduct this experiment and Mick Sibley, who also maintained the health of our pigeons. The experiment was part of a research program approved by The University of Auckland Animal Ethics Committee.

Reprints may be obtained from either author, Department of Psychology, The University of Auckland, Private Bag 92019, Auckland, New Zealand (e-mail: m.davison@auckland.ac.nz or d.elliffe@auckland.ac.nz).

cation in strict-alternation concurrent schedules should be more extreme than in random-alternation concurrent schedules because in the former, high reinforcer rates are always followed by low reinforcer rates, and vice versa. An alternative view might note that animals allocate time in concurrent VI VI schedules in such a way that local reinforcer rates (reinforcers divided by time spent responding) are usually the same between components (e.g., see review by Davison & McCarthy, 1988). If the following-component effect depends on local reinforcer rates, performance in a concurrent-schedule alternative should not be affected by the predictable following-component reinforcer rate.

Performance in concurrent schedules is usually described by the generalized matching law (Baum, 1974, 1979). In this, the ratio of responses (or times spent responding) to two alternatives is a power function of the ratio of obtained reinforcers from the two alternatives. In logarithmic form

$$\log \frac{B_1}{B_2} \quad \text{or} \quad \log \frac{T_1}{T_2} = a \log \frac{R_1}{R_2} + \log c. \quad (1)$$

In this equation, B refers to behavior frequency, T to time allocated, and R to reinforcer frequency for Alternatives 1 and 2. $\log c$ measures any constant proportional preference or bias to one alternative or the other, and a is a constant that measures the change in response ratios proportionally to the change in reinforcer ratios (termed *sensitivity to reinforcement*). For standard concurrent VI VI schedules, the value of a is usually about 0.8, and $\log c$ is zero if there is no bias (Baum, 1979).

One way of deciding whether the reinforcer rate in the following component affects responding in the current component is to compare conventional strict-alternation concurrent-schedule performance with performance on concurrent schedules in which alternatives randomly follow other alternatives. This, of course, can be done only with switching-key concurrent-schedule arrangements. Also and Davison (1991) used a two-alternative concurrent VI VI random-alternation procedure in an experiment that varied the discriminability of the two components by varying the stimuli that signaled the components. They used this procedure because they

were concerned about previous findings by Miller, Saunders, and Bourland (1980), who varied the discriminability of the stimuli that signaled the two schedules in two-alternative switching-key concurrent schedules. Miller et al. found that a , the value of sensitivity to reinforcement in Equation 1, was directly related to the physical disparity of the stimuli. When the stimuli were identical, however, the value of a was not zero, but was positive for their 2 subjects: 0.17 and 0.17 for response allocation and 0.30 and 0.20 for time allocation. This differential behavior between alternatives must have been controlled by the delivery of reinforcers rather than by the identical stimuli. That is, the subjects apparently developed a win-stay lose-shift strategy (Davison & Jenkins, 1985).

Also and Davison (1991) examined stimulus-response relations in concurrent VI VI directly by using a random-alternation (rather than strict-alternation) switching procedure that prevented subjects from discriminating between the alternatives on the basis of reinforcer frequencies. In this procedure, each switch randomly produced either the same or the alternative stimulus-schedule combination. The stimulus and schedule combination also changed randomly after each reinforcer. When the stimuli that signaled the schedules were highly discriminable, performance appeared to be identical with that produced by the usual strict-alternation procedure. That is, there seemed to be no effect of the following component reinforcer rate; however, this conclusion relies on comparisons between experiments rather than a direct demonstration using the same subjects.

A further finding suggests that the alternation rule might have an effect. Murrell (1995) reported an experiment that arranged a three-alternative switching-key concurrent VI VI VI schedule with switches producing each alternative with a probability of .33. He found that preference between two constant alternative reinforcer rates was affected by the value of the third-alternative reinforcer rate. Davison and Hunter (1976) previously showed that the constant-ratio rule (Luce, 1959) applied to the three-key procedure. This difference in results between ways of arranging three-alternative concurrent schedules could be due to a following-com-

ponent effect: If the sequence of alternatives visited is forced, performance may differ from that obtained when the next component can be chosen by the subject. This suggestion implies consistent patterns of visits in three-key concurrent VI VI VI, but we have not found any analysis of such patterns in the literature. Informal observation in our laboratory has shown high probabilities of moving both ways between the highest and second-highest reinforcer rates; low probabilities of moving from the highest to the lowest reinforcer rates; very high probabilities of moving between the lowest and the highest reinforcer rates; and essentially zero probabilities of moving either way between the second highest and lowest reinforcer rates. Independent of possible following-component effects, Murrell's finding might also be interpreted as a difference in performance when following alternatives are predictable to the subject by means of its own selection of the next alternative versus when next alternatives are unpredictable.

With some indication that following-component effects may occur in concurrent VI VI performance and only limited evidence to the contrary (Alsop & Davison, 1991), the present experiment was designed to provide a within-subject comparison of the effects of strict alternation versus random alternation of alternatives on switching-key concurrent VI VI performance. Further, we asked whether the predictability of the next component affects choice by either signaling or not signaling the next component in both strict- and random-alternation procedures. We varied the concurrent-schedule reinforcer ratios under four switching rules. In Part 1, we signaled the next component in a random-alternation concurrent VI VI schedule. In Part 2, we removed the differential stimuli that signaled the next alternative. In Part 3, we arranged strict-alternation concurrent VI VI schedules. In Part 4, we continued to arrange strict alternation, but reinstated the differential stimuli signaling the next alternative. These manipulations allowed us to answer the following questions: (a) Does random-alternation concurrent VI VI performance differ from strict-alternation performance (Part 2 vs. Part 3)? (b) In random-alternation concurrent VI VI, does signaling the next component (making it predictable) have an effect

on performance (Part 1 vs. Part 2)? (c) If it does, is signaled random-alternation performance similar to conventional strict-alternation performance (Part 2 vs. Parts 3 and 4)? In general, if there is a following-component effect, separate analyses of current-alternative performance as a function of the next component should produce differences between conditions in which the next alternative was either signaled or predictable (Parts 1, 3, and 4) compared with performance when it was neither signaled nor predictable (Part 2).

METHOD

Subjects

Six homing pigeons (numbers 51 through 56), were maintained at $85\% \pm 15$ g of their free-feeding body weights. The subjects had previously served in an experiment on signaled travel times in concurrent VI VI schedules using the same apparatus (Davison & Elliffe, 2000). Pigeon 55's response rate decreased very substantially during Part 4 of the experiment, and its data have been excluded from the analysis of that part.

Apparatus

The experiment was conducted in the subjects' home cages. Each subject was housed in a cage 375 mm high, 370 mm wide, and 370 mm deep. On one wall was an interface panel with four pecking keys (20 mm diameter). They were 70 mm apart and 220 mm above a wooden perch (20 mm from the floor and 100 mm from the interface) in front of the panel. The keys required about 0.1 N for operation. Also on the panel was a magazine aperture (40 mm by 40 mm), located 60 mm above the perch. During reinforcement, all keylights were extinguished, and the hopper containing wheat was raised and illuminated for 3 s. The three response keys on the left were used in the experiment. Of these keys, the center (main) key was illuminated red or green according to which of the concurrent schedules was in effect. The keys on either side of this key could be illuminated yellow. These side keys were the switching keys. In the home cage, the pigeons could see and hear other pigeons working on other experiments, but no personnel entered the room while the experiments were running. Sessions began at 1:30 a.m. daily, which was 30 min

after the room lights were turned on. The 6 subjects were run consecutively, and the room lights were extinguished at 3:30 p.m.. At 10:00 a.m. each day, the subjects were fed mixed grain sufficient to maintain their designated body weights.

Procedure

Because the subjects had extensive experience pecking on concurrent VI VI schedules, no training was required, and Condition 1 began immediately. Sessions began with the illumination of the switching key or keys and, with equal probability, either the red or the green main key and its associated schedule. Pecks on the center key were occasionally followed by 3-s access to the hopper containing wheat. Pecking a switching key caused the main and switching keys to extinguish for 0.1 s and then reilluminate. In Part 1, the main-key schedules and stimuli alternated randomly ($p = .5$) following a switch. Only one switching key was illuminated at any time, and its location (to the left or the right of the main key) signaled whether the red or green alternative would be presented following the next switch. The switching key in operation at the start of the session was chosen randomly ($p = .5$). In Part 2, alternatives were also changed randomly after a switch, but both switching keys were always lit and operative with the main key, so the next component was not signaled. Part 3 arranged strict alternation between main-key schedules and stimuli after a switch, with both switching keys always lit and operative. In Part 4, the main-key schedule and stimulus alternated strictly after a switch, but the location of the switching key again signaled which alternative would follow a switch, as in Part 1. In all conditions, the same main key and switching key were presented again after a reinforcer.

Over all conditions of the experiment, reinforcers were arranged on an average of every 30 s by interrogating a probability generator set at .0333 every 1 s. When a reinforcer was arranged in this way, it was then allocated to the red or green alternative according to a defined probability (Table 1). A reinforcer arranged in this way remained available until taken, and no further reinforcers could be arranged until it was taken. The concurrent schedules were thus dependently arranged (Stubbs & Pliskoff, 1969). A

Table 1

Sequence of experimental conditions, relative red-green reinforcer frequency, and number of training sessions in each condition. The overall reinforcer rate was two per minute in all conditions.

Condition	Relative reinforcers red/(red + green)	Sessions
Part 1: Signaled random alternation		
1	.5	— ^a
2	.9	22
3	.3	26
4	.8	23
5	.1	33
16	.1	26
Part 2: Unsignaled random alternation		
6	.5	26
7	.9	30
8	.3	26
9	.8	28
10	.1	26
Part 3: Unsignaled strict alternation		
11	.5	24
12	.9	22
13	.3	25
14	.8	24
15	.1	22
Part 4: Signaled strict alternation		
17	.5	24
18	.9	25
19	.3	28
20	.8	30
21	.1	33

^a Due to an oversight, the number of sessions conducted in Condition 1 was not recorded. It was at least 25 sessions.

changeover delay of 2 s operated in all conditions. Condition 16 replicated Condition 5 of Part 1.

Sessions ended in blackout after 50 reinforcers had been delivered or after 2,500 s, whichever came first. All experimental conditions and data collection were arranged using a remote IBM PC-compatible computer running MED-PC[®] software.

Conditions were changed when the data had reached a defined stability criterion. For this criterion, the first 10 sessions after a condition change were ignored. Then, starting with Sessions 11 and 12, relative response rates (red responses divided by total session responses) were calculated for each session. The direction of change in relative response rates (i.e., towards indifference or away from indifference) between pairs of consecutive sessions was then evaluated. When this direc-

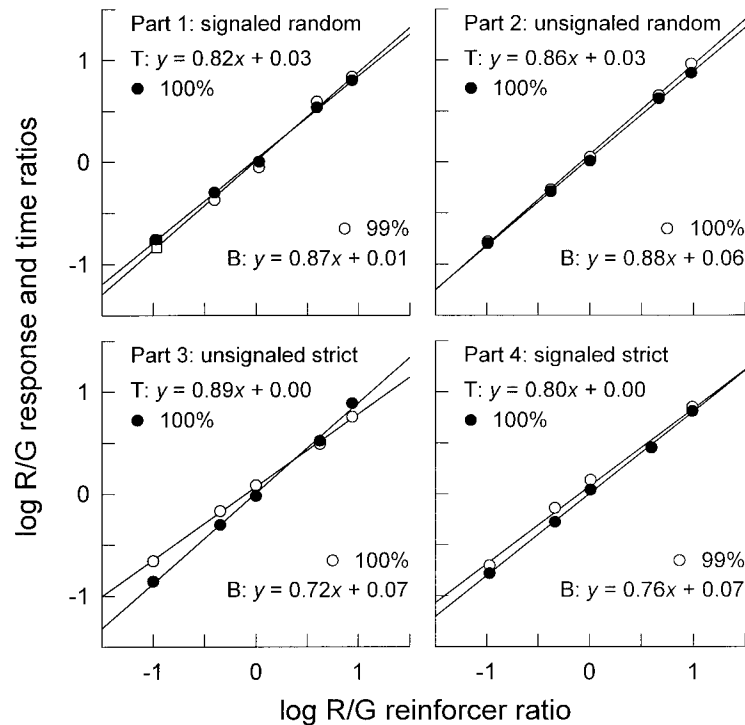


Fig. 1. \log_{10} red-green response (filled symbols) and time (open symbols) ratios as functions of \log_{10} red-green reinforcer ratios, averaged across pigeons and plotted separately for each part, or switching arrangement. Squares indicate data from the replication (Condition 16, Part 1). The lines indicate the least-squares fits of Equation 1, and the equation of and percentage of variance accounted for by each line are shown.

tion of change had reversed five times, performance for that subject was considered to be stable. When this criterion had been met for all 6 subjects, the condition was changed for all subjects. Thus, at least 17 sessions were required for stability. The numbers of sessions actually conducted in each condition are shown in Table 1.

The data collected were the times at which every event (response, reinforcer, and switch) occurred. These files, for the last five sessions of each condition, were analyzed to provide the data reported here (see Appendix).

RESULTS

Table 2 shows the results of least squares fits of the generalized matching law (Equation 1). Analyses of both response and time allocation were conducted separately for each part of the experiment or switching arrangement. As noted previously, Pigeon 55's data from Part 4 have been excluded, and that pigeon's data have been completely excluded

from comparisons between parts. Figure 1 shows generalized-matching plots for the mean data across subjects in each part.

Fits of Equation 1 were extremely good, with the percentage of variance accounted for by the fit (%VAC) exceeding 97% in 41 of the 46 fits and 91% in all fits. The overall mean %VAC was 98% for response allocation and 99% for time allocation.

Values of bias ($\log c$ in Equation 1) were generally very close to zero, except for Pigeon 54. Across pigeons and measures of preference, there was a very small ($M = 0.04$) but consistent (binomial $p < .05$) bias towards the red main-key schedule. Repeated measures analyses of variance (ANOVAs) and matched pairs t tests showed no differences between biases between parts or between response and time allocation.

Figure 2 shows scatter plots of time-allocation sensitivity (a in Equation 1) plotted against response-allocation sensitivity for each bird in each part. Undermatching, or values of $a < 1.0$, occurred in 43 of the 46 analyses

Table 2

Generalized-matching analysis of the combined (next red and next green) data from all parts of the experiment, showing least-squares estimates of sensitivity to reinforcement (a) and bias ($\log c$) and the percentage of variance accounted for by the fit (%VAC), for both response and time allocation and for each subject.

	Pigeon 51		Pigeon 52		Pigeon 53		Pigeon 54	
	B	T	B	T	B	T	B	T
Part 1: Signaled random alternation								
a	0.85	0.74	0.81	0.90	1.14	0.93	0.77	0.74
$\log c$	-0.02	0.03	-0.03	0.03	0.06	0.03	0.25	0.13
%VAC	99	100	98	99	100	100	100	99
Part 2: Unsignaled random alternation								
a	0.86	0.68	0.76	0.93	1.04	0.94	0.83	0.83
$\log c$	0.17	0.05	-0.08	-0.02	0.08	0.03	0.26	0.06
%VAC	100	100	99	98	100	100	99	99
Part 3: Unsignaled strict alternation								
a	0.63	0.79	0.68	0.89	0.75	0.88	0.58	0.91
$\log c$	0.06	0.04	0.06	0.05	0.05	0.03	0.31	0.00
%VAC	99	100	99	100	95	98	98	99
Part 4: Signaled strict alternation								
a	0.67	0.72	0.89	0.98	0.80	0.87	0.70	0.64
$\log c$	-0.06	0.01	0.13	0.08	0.04	0.01	0.13	-0.08
%VAC	100	100	99	99	98	99	96	96

Note. B is behavior frequency; T is time allocated (see Equation 1).

(binomial $p < .05$). Across pigeons and parts, the mean response-allocation and time-allocation sensitivities were 0.81 and 0.84, respectively. Repeated measures ANOVAs showed that response-allocation sensitivities differed across parts, $F_{3, 12} = 5.62$, $p < .05$, but that time-allocation sensitivities did not. Combining data across parts, a matched pairs t test showed no difference between response and time sensitivities. Time sensitivities, however, exceeded the corresponding response sensitivities both in Parts 3 and 4 combined, which arranged strict alternation between main-key schedules, matched pairs $t_{10} = 3.53$, two-tailed $p < .05$, and in Part 3 taken in isolation (unsignaled strict alternation) matched pairs $t_5 = 4.06$, two-tailed $p < .05$. This difference is apparent in the bottom panel of Figure 2, in which all data points but one (Pigeon 54, Part 4) fall above the major diagonal. Time and response sensitivities did not differ significantly in Parts 1 and 2, which arranged random alternation between main-key schedules, or in Part 4 (signaled strict alternation) when analyzed separately (see Figure 2). Finally, a repeated measures ANOVA showed that the difference between response and

time sensitivities differed across parts, $F_{3, 12} = 7.88$, $p < .05$.

The data from Part 1, which arranged signaled random alternation between main-key schedules, may be further decomposed before analysis according to the generalized matching law. Three possible decompositions are apparent, according to whether the post-switch alternative (i.e., the alternative that would be produced by a switching-key response) was to be (a) red or green, (b) the higher or lower reinforcer rate of the two alternative schedules, or (c) the same as or different from the current alternative. All three of these analyses were tried, but the third seemed less informative than the first two and so has been omitted.

Part 2 also arranged random alternation and thus may be analyzed in the same ways. The nature of the next alternative, however, should not have affected behavior in Part 2 because it was unsignaled; therefore, Part 2 serves as a control for Part 1. Tables 3 and 4 present generalized-matching analyses of response- and time-allocation data from Parts 1 and 2 categorized according to the postswitch alternative in the first two ways described

Table 2
(Extended)

Pigeon 55		Pigeon 56	
<i>B</i>	<i>T</i>	<i>B</i>	<i>T</i>
0.81	0.72	0.87	0.87
-0.09	-0.07	-0.11	0.01
92	98	93	99
1.03	0.92	0.76	0.83
0.08	0.06	-0.08	0.01
99	98	99	100
0.90	0.92	0.78	0.94
0.02	0.00	-0.11	-0.10
99	100	100	100
		0.72	0.78
		0.13	-0.02
		98	100

above. Data from Conditions 1 and 6, which arranged equal reinforcer rates in red and green, were necessarily excluded from all analyses with respect to whether the post-switch reinforcer rate was to be the higher or lower rate.

Two-tailed matched pairs *t* tests were used to assess the significance of possible differences between these generalized-matching fits according to the nature of the next alternative. In Part 1, response-allocation biases favored the color of the next signaled alternative: next red: mean $\log c = 0.17$, next green: mean $\log c = -0.17$; $t_5 = 3.93$, $p < .05$. Time-allocation biases showed the same effect: next red: mean $\log c = 0.19$, next green: mean $\log c = -0.15$; $t_5 = 4.55$, $p < .05$. However, neither response nor time biases differed with respect to the color of the next alternative when that alternative was un signaled (Part 2). Sensitivity was not consistently related to the color of the next alternative, whether signaled or un signaled (see Table 3).

Response-allocation sensitivities were substantially and significantly higher, $t_5 = 3.36$, $p < .05$, when the postswitch alternative was signaled to be the higher (mean $a = 1.01$) rather than the lower (mean $a = 0.62$) reinforcer rate (see Table 4, Part 1). Time-allocation

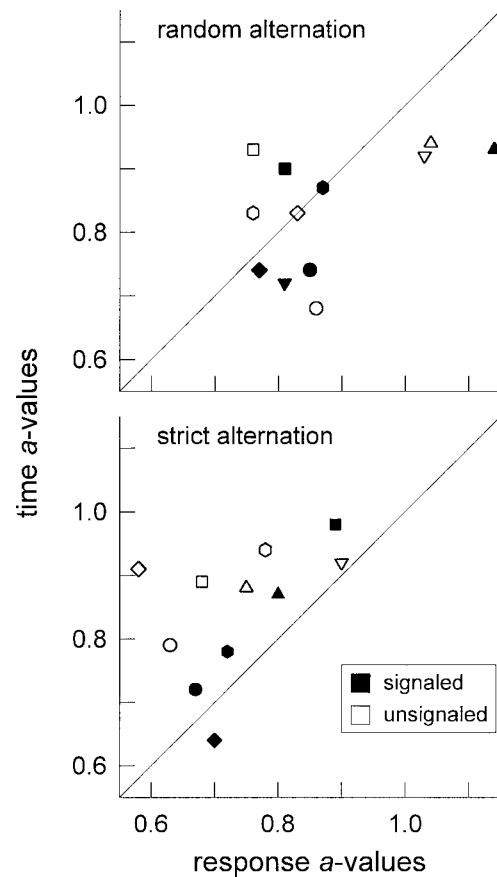


Fig. 2. Time-allocation sensitivities to reinforcement (a in Equation 1) plotted against response-allocation sensitivities. The top panel shows data from the random-alternation procedures (Parts 1 and 2), and the bottom panel shows data from the strict-alternation procedures (Parts 3 and 4). Filled and open symbols denote signaled and un signaled alternation respectively, and different symbol shapes indicate data from different pigeons (circles: Pigeon 51; squares: Pigeon 52; upright triangles: Pigeon 53; diamonds: Pigeon 54; inverted triangles: Pigeon 55; hexagons: Pigeon 56).

sensitivities showed the same effect: mean a values = 0.95 and 0.57, $t_5 = 3.47$, $p < .05$. None of the other comparisons in Table 4 was significant.

Tables 3 and 4 show that Equation 1 describes the data from Part 1 less well when decomposed according to the next signaled alternative (overall mean %VAC = 94) than when combined across next alternatives (see Table 2, overall mean %VAC = 98). The data from Part 2 (un signaled random alternation) produced similar fits when decomposed (overall mean %VAC = 99) or when com-

Table 3

Generalized-matching analyses of response and time allocation in Parts 1 and 2, decomposed according to whether the postswitch alternative was to be red (R) or green (G), as functions of the combined reinforcer ratio across postswitch alternatives.

	Pigeon 51		Pigeon 52		Pigeon 53		Pigeon 54		Pigeon 55		Pigeon 56	
	R	G	R	G	R	G	R	G	R	G	R	G
Part 1: Signaled random alternation, response allocation												
a	0.85	0.78	0.63	0.94	0.97	1.04	0.93	0.41	0.49	0.95	0.97	0.73
$\log c$	0.21	-0.26	0.08	-0.14	0.40	-0.32	0.32	0.16	0.01	-0.20	0.00	-0.28
%VAC	98	94	94	99	94	100	96	73	55	97	96	85
Part 2: Unsignaled random alternation, response allocation												
a	0.92	0.78	0.74	0.77	1.00	1.08	0.80	0.87	0.99	1.06	0.81	0.70
$\log c$	0.16	0.18	-0.15	-0.01	0.07	0.07	0.28	0.25	0.09	0.06	-0.04	-0.11
%VAC	100	99	98	99	100	100	99	99	99	98	97	100
Part 1: Signaled random alternation, time allocation												
a	0.78	0.65	0.64	1.10	0.79	0.82	0.95	0.28	0.58	0.79	0.95	0.73
$\log c$	0.26	-0.22	0.13	-0.04	0.34	-0.29	0.21	-0.01	0.08	-0.21	0.09	-0.14
%VAC	99	95	99	98	97	100	99	73	84	99	96	99
Part 2: Unsignaled random alternation, time allocation												
a	0.74	0.62	0.92	0.94	0.89	0.98	0.79	0.86	0.89	0.94	0.88	0.78
$\log c$	0.02	0.08	-0.07	0.03	0.02	0.04	0.07	0.05	0.08	0.04	0.05	-0.02
%VAC	99	99	98	98	99	100	100	99	99	97	99	100

bin (see Table 2, overall mean %VAC = 99). With few exceptions, the fits to the decomposed data were generally very good.

The generalized-matching fits described above were conducted using the combined

red-green reinforcer ratio across both postswitch alternatives. Because some differences between the fits preceding the two alternatives did emerge in Part 1 but not in Part 2, it seems clear that behavior was under dis-

Table 4

Generalized-matching analyses of response and time allocation in Parts 1 and 2, decomposed according to whether the reinforcer rate in the postswitch alternative was to be higher (H) or lower (L) than in the current alternative, as functions of the combined reinforcer ratio across postswitch alternatives.

	Pigeon 51		Pigeon 52		Pigeon 53		Pigeon 54		Pigeon 55		Pigeon 56	
	H	L	H	L	H	L	H	L	H	L	H	L
Part 1: Signaled random alternation, response allocation												
a	1.10	0.52	0.91	0.66	1.46	0.57	0.74	0.60	0.86	0.62	1.00	0.74
$\log c$	0.00	-0.08	-0.11	0.07	0.03	0.07	0.39	0.02	-0.20	0.08	-0.00	-0.12
%VAC	98	97	98	93	99	89	87	94	78	94	92	98
Part 2: Unsignaled random alternation, response allocation												
a	0.85	0.86	0.64	0.87	1.06	1.02	0.85	0.81	1.02	1.02	0.82	0.69
$\log c$	0.18	0.09	-0.08	-0.07	0.03	0.07	0.21	0.25	0.05	0.11	-0.02	-0.07
%VAC	100	99	100	99	100	100	100	99	99	99	98	99
Part 1: Signaled random alternation, time allocation												
a	1.03	0.40	0.94	0.80	1.20	0.42	0.70	0.53	0.84	0.53	0.96	0.73
$\log c$	0.07	-0.05	-0.11	0.20	0.02	0.03	0.32	-0.12	-0.12	0.01	0.06	-0.07
%VAC	100	98	100	97	99	96	89	94	89	96	96	95
Part 2: Unsignaled random alternation, time allocation												
a	0.64	0.72	0.85	1.01	0.93	0.94	0.84	0.80	0.92	0.90	0.90	0.76
$\log c$	0.08	-0.00	-0.03	-0.02	0.01	0.06	0.04	0.08	0.03	0.07	0.05	0.01
%VAC	100	99	99	98	100	100	100	99	99	97	100	99

Table 5

Generalized-matching analyses of log response and time ratios as functions of local log reinforcer ratios in Part 1, decomposed according to whether the postswitch alternative was to be red (R) or green (G) or of higher (H) or lower (L) reinforcer rate than the current alternative.

	Pigeon 51		Pigeon 52		Pigeon 53		Pigeon 54		Pigeon 55		Pigeon 56	
	R	G	R	G	R	G	R	G	R	G	R	G
Response allocation												
<i>a</i>	0.80	0.91	0.86	0.70	1.08	1.13	0.80	0.61	0.65	0.85	0.87	0.86
log <i>c</i>	0.05	-0.08	-0.01	-0.07	0.09	0.01	0.25	0.27	-0.04	-0.13	-0.03	-0.22
%VAC	98	98	96	97	99	97	99	95	69	96	97	82
Time allocation												
<i>a</i>	0.74	0.76	0.84	0.82	0.87	0.90	0.80	0.39	0.71	0.71	0.85	0.87
log <i>c</i>	0.12	-0.08	0.03	0.05	0.09	-0.03	0.15	0.06	0.02	-0.15	0.07	-0.07
%VAC	100	99	95	97	100	98	100	82	93	99	99	99
	H	L	H	L	H	L	H	L	H	L	H	L
Response allocation												
<i>a</i>	0.91	0.72	0.77	0.74	1.13	1.08	0.69	0.78	0.83	0.70	0.98	0.81
log <i>c</i>	-0.06	-0.02	0.02	-0.05	0.03	0.08	0.29	0.19	-0.11	0.03	-0.07	-0.04
%VAC	99	96	95	98	100	95	97	100	87	94	95	99
Time allocation												
<i>a</i>	0.85	0.56	0.79	0.89	0.94	0.75	0.64	0.69	0.80	0.62	0.93	0.81
log <i>c</i>	0.01	0.00	0.03	0.05	0.02	0.03	0.22	0.03	-0.04	-0.03	-0.01	0.02
%VAC	100	98	96	99	100	92	93	99	96	100	99	99

criminative control by the alternative that would follow a switch when that alternative was signaled. It may therefore be more appropriate to analyze behavior in Part 1 separately with respect to the reinforcer ratio obtained preceding each alternative (e.g., to regress the red-green response ratio when the next alternative was to be red against the red-green reinforcer ratio when the next alternative was to be red). We call this a *local* reinforcer ratio. Table 5 presents the results of time and response analyses of Part 1 identical to those reported in Tables 3 and 4 using the local rather than combined reinforcer ratio.

In the local analyses, both response-allocation, $t_5 = 3.19, p < .05$ and time-allocation $t_5 = 3.86, p < .05$, biases were towards the color of the signaled postswitch alternative, although the difference between biases was less than in the combined analyses (responses: next-red mean log $c = 0.05$, next-green mean log $c = -0.04$; time: next-red mean log $c = 0.08$, next-green mean log $c = -0.04$). As in the combined analysis, no other effects of the postswitch color reported in Table 5 were statistically significant. The local analyses pro-

duced no significant differences in sensitivity or bias with respect to whether the signaled postswitch alternative was to be the higher or lower reinforcer rate.

Averaged across both decompositions and across response and time allocation, the mean %VAC in the local reinforcer ratio analyses of Part 1 was 96%, compared with means of 98% for the overall generalized-matching analysis (see Table 2) and 94% for the combined reinforcer ratio analyses (see Tables 3 and 4).

Figure 3 shows generalized-matching analyses of the mean log response and reinforcer ratios across pigeons for both the signaled next-red versus next-green and next-higher-rate versus next-lower-rate decompositions of behavior described above, in terms of both combined and local reinforcer ratios. Figure 4 shows the same analyses for time allocation. Note that the parameters of Equation 1 shown in these figures sometimes differ slightly from the means reported above. This is because the figures show fits to the mean data rather than means of the fits to individual data.

Figures 3 and 4 show that, within condi-

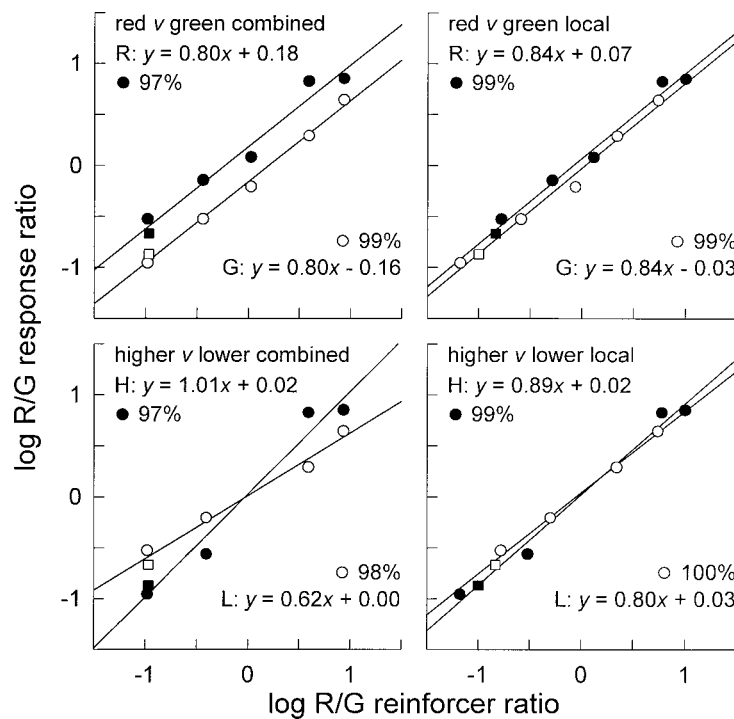


Fig. 3. \log_{10} red–green response ratios as functions of \log_{10} red–green reinforcer ratios from Part 1, averaged across pigeons. Filled and open symbols denote data obtained when the postswitch alternative was to be red or green (top row) or of higher or lower reinforcer rate (bottom row). Both combined (left) and local (right) reinforcer-ratio analyses are shown. Squares indicate data from the replication. Lines, equations, and percentage of variance accounted for describe the least-squares fits of Equation 1.

tions, local reinforcer ratios differed according to the postswitch alternative. Local \log reinforcer ratios shifted right (i.e., towards red) when the postswitch alternative was signaled to be red, and shifted left when it was signaled to be green. The mean difference between next-red and next-green \log reinforcer ratios was 0.23 \log units, across pigeons and conditions. A matched pairs t test carried out on local \log reinforcer ratios for all conditions and pigeons confirmed the reliability of the shift, $t_{35} = 3.21$, $p < .05$. The same result appears differently in the next-higher versus next-lower graphs (which plot the same data points, only sorted differently), in which the range of \log reinforcer ratios is considerably greater when the postswitch reinforcer rate is signaled to be the higher rate.

Figures 1, 3, and 4 show that the replication (Condition 16) produced data similar to the original condition (Condition 5, Part 1).

Figure 5 shows the mean interchangeover times (ICTs) across pigeons as functions of

the proportion of reinforcers obtained from the red alternative in each condition. On each graph, separate ICT functions are shown according to the current alternative and, in the random-alternation conditions, the postswitch alternative. The two left graphs and the bottom right graph all plot ICTs as functions of the combined relative reinforcer rate across both postswitch alternatives. The top right graph plots ICTs as functions of the local relative reinforcer rate, as discussed above.

All graphs show the typical pattern of ICTs in concurrent schedules, in which time spent on an alternative increases in a monotonic, positively accelerated manner as the proportion of reinforcers obtained from that alternative increases. Parts 2 to 4 (bottom row of Figure 5) all produced similar ICT functions. However, ICTs were slightly but significantly shorter in Part 4 (signaled strict alternation) than in the equivalent conditions of Part 3 (unsignaled strict alternation) when pooled

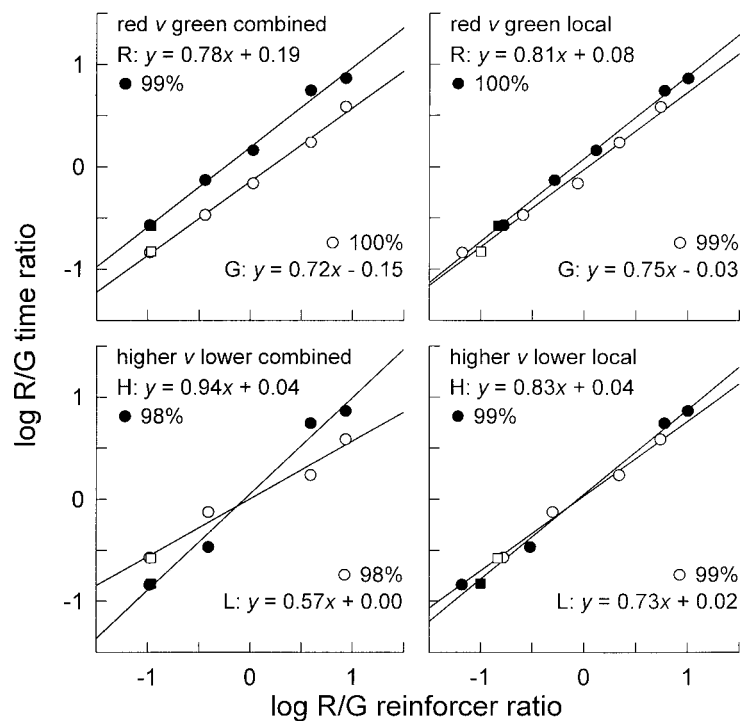


Fig. 4. \log_{10} red-green time ratios as functions of \log_{10} red-green reinforcer ratios from Part 1, averaged across pigeons and presented as in Figure 3.

over five reinforcer ratios, 5 pigeons (excluding Pigeon 55), and two current alternatives, matched pairs $t_{49} = 2.03$, two-tailed $p < .05$. This difference may be seen in the mean data in the bottom right graph of Figure 5.

As expected, ICTs were almost identical before each of the two postswitch alternatives when those alternatives were unsigned (Part 2, bottom left graph). However, signaling the postswitch alternative in the random alternation procedure (Part 1) resulted in ICTs that were on average about 40% less when the postswitch alternative was to be different from, rather than the same as, the current alternative. This difference was significant across the six reinforcer ratios, 6 pigeons, and two current alternatives, matched pairs $t_{71} = 3.50$, two-tailed $p < .05$, and is visible in the top left graph of Figure 5.

Because the different behavior preceding each signaled alternative was associated with different reinforcer rates, however, it may again be better to plot ICTs as functions of the local, rather than the combined, relative reinforcer rate. The top right graph in Figure

5 shows this analysis. As discussed above, relative reinforcer rate shifted right (i.e., towards red) when the postswitch alternative was signaled to be red compared to when it was signaled to be green. When analyzed in this way, there appears to be no systematic difference between the functions relating ICT to relative reinforcer rate for the two postswitch alternatives.

DISCUSSION

When the data were analyzed irrespective of the next alternative, arranging random alternation between concurrent schedules produced sensitivity (a in Equation 1) similar to that seen in strictly alternating schedules both here and in the literature, except that response-allocation sensitivity was a little higher in the random-alternation procedure (see Figures 1 and 2 and Table 2). Although time-allocation sensitivities usually exceed response-allocation sensitivities (e.g., Elliffe & Alsop, 1996; Taylor & Davison, 1983), Figures 1 and 2, and the supporting significance tests, suggest that this difference may be specific to

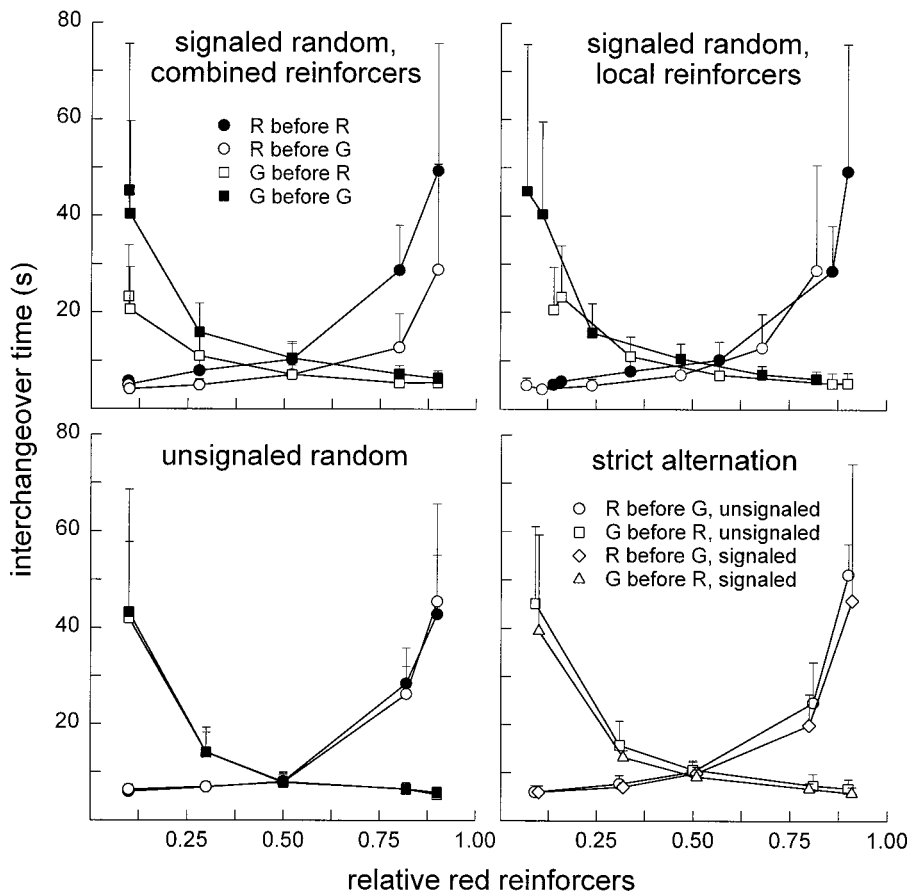


Fig. 5. Mean ICTs as functions of relative red reinforcers in each condition averaged across pigeons. The top row shows data from Part 1, signaled random alternation, analyzed with respect to both the combined (left) and local (right) relative reinforcer rate. The bottom left graph shows data from Part 2, unsignaled random alternation, and the bottom right graph shows data from both unsignaled and signaled strict alternation (Parts 3 and 4). Filled and open symbols denote data obtained when the postswitch alternative was to be the same as, or different from, the current alternative, respectively. Circles (diamonds in Part 4) denote ICTs on the red alternative, and squares (triangles in Part 4) denote green ICTs. The data from the replication are not differentiated from the original data. The error bars show + 1 standard deviation of the individual pigeon's mean ICTs in each condition ($n = 5$ or 6).

the conventional unsignaled strict-alternation method of arranging concurrent schedules. Arranging random alternation appears to eliminate the difference between these measures of preference, probably by increasing response-allocation sensitivities to a level similar to time-allocation sensitivities (Figure 2).

Different ways of analyzing the data from the signaled random-alternation conditions (Part 1) according to the postswitch alternative, however, produced different conclusions (see Figures 3 and 4). For the combined reinforcer-ratio analysis, a differential bias resulted if the data were decomposed according to whether the next alternative was red

or green. If the data were decomposed according to whether a switch produced the higher or the lower reinforcer rate, differential sensitivity resulted. When preference was considered as a function of the local reinforcer ratios only, however, these differences either disappeared (sensitivity) or were reduced in magnitude (bias). This suggests a parsimonious interpretation. Because behavior differed in the presence of each signal (Figures 3 through 5), it seems reasonable to suppose that the signals were discriminated. Therefore, the distributions of reinforcers obtained in the presence of each signal might also have been discriminated. As Figures 3

and 4 show, those distributions of reinforcers differed in such a way that a common generalized-matching function described the relation between preference and each local reinforcer distribution (Figures 3 and 4 and Table 5). Some support is lent to this interpretation by the fact that Equation 1 fitted the data more precisely when analyzed in terms of local ratios than combined reinforcer ratios.

Similar reasoning may be applied to the patterns of ICTs shown in Figure 5. When plotted with respect to the combined relative reinforcer rate, the ICTs from Part 1 seem difficult to explain. The ICT functions from Parts 2, 3, and 4 were all very similar; that is, unsignaled random alternation produced similar patterns of changing over to strict alternation, whether signaled or unsignaled. Part 1 may be thought of as comprising two signaled alternation rules, strict alternation and nonalternation (when a switching-key response does not produce a change in schedule). If these rules are discriminated, we might predict that ICTs obtained when strict alternation was in effect would be like those obtained under an overall strict-alternation procedure, and that ICTs obtained when switches were signaled to be ineffective might differ from both. The top left graph in Figure 5 shows precisely the opposite result. The two functions obtained when switches were signaled to be ineffective (i.e., red ICTs before signaled red, and green before green) are like those obtained in Parts 3 and 4, and those obtained when strict alternation was signaled (i.e., red before green, and green before red) show markedly shorter ICTs. That is, the patterns of similarity in the ICT data between parts of the experiment do not coincide with the similarities in switching contingency.

Analyzing ICTs with respect to local reinforcers, however, clarifies matters. The top right graph of Figure 5 shows no systematic difference between the ICT functions obtained before the two postswitch alternatives. Two functions, one for each current alternative, seem enough to describe the data. Again, the most parsimonious conclusion is that the relation between ICT and relative reinforcement was the same for both the postswitch alternatives, but that the distributions of relative reinforcement differed.

Given that the concurrent VI schedules used here were dependently arranged, it is not immediately obvious why the distribution of reinforcers should be affected by the signaled postswitch alternative. We suggest the following mechanism. Suppose that the current alternative is red. If the signaled postswitch alternative is to be green, the probability of a reinforcer following a switch to green is relatively high because the green VI schedule has been running while the subject has been responding in red (Dreyfus, Dorman, Fetterman, & Stubbs, 1982). That is, there is an additional contingency in favor of switching. But if the postswitch alternative is to be red, there is no such added contingency. We would therefore predict that the subject would stay longer in red before switching to red than before switching to green. Figure 5 shows that this is what happened in every condition. This means that more of the reinforcers arranged by the red VI schedule will be obtained when the postswitch alternative is to be red, simply because more time is spent in red preceding red than in red preceding green. This predicts a shift in local relative red reinforcement (Figure 5) or local log reinforcer ratio (Figures 3 and 4) towards red when the postswitch alternative is also to be red.

Three other features of the ICT data merit brief consideration. First, the relation between ICT and relative reinforcer rate agrees with previous concurrent-schedule research. The roughly symmetrical pair of positively accelerated functions relating ICT on each alternative to relative reinforcement on that alternative means that switches were most frequent when equal reinforcers were obtained on each alternative (e.g., Brownstein & Pliskoff, 1968; Stubbs & Pliskoff, 1969; Tustin & Davison, 1979).

Second, comparison of the bottom two graphs in Figure 1 suggests that arranging unsignaled random, rather than strict, alternation made very little difference to ICT. This is surprising, given previous demonstrations of prospective control by loss of reinforcers from the postswitch alternative in concurrent schedules (e.g., Davison, 1991; Davison & Elliffe, 2000). Dreyfus et al.'s (1982) argument also predicts longer ICTs in random alternation than in strict alternation. This is because half the switches in random alternation will

result in a return to the same alternative, so that the added contingency in favor of switching must be reduced. Although entirely speculative, a possible explanation is that "attempted," ineffective switching responses that returned the subject to the same alternative were closely followed by another switching response, producing a number of short ICTs and thereby decreasing the overall mean ICT.

Finally, the slight but reliable decrease in ICT when, under strict alternation, the postswitch alternative was explicitly signaled is surprising. In unsignaled strict alternation, because the postswitch alternative is completely specified by the color of the current alternative, arranging differentiated switching responses carries no extra information and should not affect behavior. The fact that a small effect did emerge shows that stimulus control over switching responses in the unsignaled procedure must be incomplete.

On balance, however, the strong similarities between behavior under unsignaled random alternation and both forms of strict alternation suggest that these procedures are more or less equivalent, at least if the stimuli signaling the alternatives are discriminable (cf. Alsop & Davison, 1991; Miller et al., 1980), and indicate that the concerns raised in the introduction are largely unfounded. This is reassuring, in that it justifies comparisons between experiments that have used different procedures. The major difference between behavior under random and strict alternation shown by the present data is that the difference between response and time allocation usually found under strict alternation appears to be eliminated under random alternation.

Throughout this experiment, control by the postswitch alternative was less than we had expected. Although signaling the next alternative appeared to produce strong control in Part 1, those effects were eliminated or greatly attenuated when local distributions of reinforcement were taken into account. In terms of both generalized matching and changing over, the simplest interpretation is that different distributions of reinforcers between alternatives arise when postswitch alternatives are signaled, that those distributions are discriminated, and that a common relation between behavior and reinforcement

continues to hold for both postswitch alternatives. We suggest that future demonstrations of control by events or contingencies following switching in concurrent schedules must consider possible indirect mechanisms in terms of changed local reinforcer distributions. Similarly, any explanation of differences between two- and three-key concurrent schedules that invokes differences in switching contingencies must also consider differences between local reinforcer distributions preceding each postswitch alternative.

REFERENCES

- Alsop, B., & Davison, M. (1991). Effects of varying stimulus disparity and the reinforcer ratio in concurrent-schedule and signal-detection procedures. *Journal of the Experimental Analysis of Behavior*, *56*, 67–80.
- Baum, W. M. (1974). On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior*, *22*, 231–242.
- Baum, W. M. (1979). Matching, undermatching, and overmatching in studies of choice. *Journal of the Experimental Analysis of Behavior*, *32*, 269–281.
- Brownstein, A. J., & Pliskoff, S. S. (1968). Some effects of relative reinforcement rate and changeover delay in response-independent concurrent schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, *11*, 683–688.
- Davison, M. (1991). Choice, changeover, and travel: A quantitative model. *Journal of the Experimental Analysis of Behavior*, *55*, 47–61.
- Davison, M., & Elliffe, D. (2000). Travel time and concurrent-schedule choice: Retrospective versus prospective control. *Journal of the Experimental Analysis of Behavior*, *73*, 65–77.
- Davison, M. C., & Hunter, I. W. (1976). Performance on variable-interval schedules arranged singly and concurrently. *Journal of the Experimental Analysis of Behavior*, *25*, 335–345.
- Davison, M., & Jenkins, P. E. (1985). Stimulus discriminability, contingency discriminability, and schedule performance. *Animal Learning & Behavior*, *13*, 77–84.
- Davison, M., & McCarthy, D. (1988). *The matching law: A research review*. Hillsdale, NJ: Erlbaum.
- 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.
- Elliffe, D., & Alsop, B. (1996). Concurrent choice: Effects of overall reinforcer rate and the temporal distribution of reinforcers. *Journal of the Experimental Analysis of Behavior*, *65*, 445–463.
- Findley, J. D. (1958). Preference and switching under concurrent scheduling. *Journal of the Experimental Analysis of Behavior*, *1*, 123–144.
- 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.

- Luce, R. D. (1959). *Individual choice behavior: A theoretical analysis*. New York: Wiley.
- Miller, J. T., Saunders, S. S., & Bourland, G. (1980). The role of stimulus disparity in concurrently available reinforcement schedules. *Animal Learning & Behavior*, 8, 635–641.
- Murrell, P. R. (1995). *Choice on three concurrent alternatives*. Unpublished master's thesis, University of Auckland, New Zealand.
- Stubbs, D. A., & Pliskoff, S. S. (1969). Concurrent responding with fixed relative rate of reinforcement. *Journal of the Experimental Analysis of Behavior*, 12, 887–895.
- Taylor, R., & Davison, M. (1983). Sensitivity to reinforcement in concurrent arithmetic and exponential schedules. *Journal of the Experimental Analysis of Behavior*, 39, 191–198.
- Tustin, R. D., & Davison, M. (1979). Choice: Effects of changeover schedules on concurrent performance. *Journal of the Experimental Analysis of Behavior*, 32, 75–91.
- Williams, B. A. (1979). Contrast, component duration, and the following schedule of reinforcement. *Journal of Experimental Psychology: Animal Behavior Processes*, 5, 379–396.
- Williams, B. A. (1981). The following schedule of reinforcement as a fundamental determinant of steady state contrast in multiple schedules. *Journal of the Experimental Analysis of Behavior*, 35, 293–310.
- Wilton, R. N., & Gay, R. A. (1969). Behavioral contrast in one component of a multiple schedule as a function of the reinforcement conditions operating in the following component. *Journal of the Experimental Analysis of Behavior*, 12, 239–246.

Received January 26, 2001

Final acceptance September 7, 2002

APPENDIX

Number of responses, time spent responding (in seconds), numbers of changeovers, and numbers of reinforcers obtained on the red and green alternatives according to whether the postswitch (next) alternative was to be red or green. The data are summed over the last five sessions of each condition.

Condition	Responses				Time (s)			
	Red		Green		Red		Green	
	next R	next G	next R	next G	next R	next G	next R	next G
Pigeon 51								
1	2,758	1,922	998	2,595	3,356	2,074	1,455	2,971
2	4,177	1,802	461	632	5,891	2,265	562	993
3	1,696	1,348	3,132	3,120	2,256	1,642	3,482	3,287
4	4,575	1,409	995	1,179	5,464	2,029	1,128	1,605
5	747	514	2,418	4,000	1,121	680	3,006	4,364
6	2,166	2,140	1,568	1,455	2,931	2,658	2,487	2,244
7	2,435	1,500	243	221	4,660	3,310	921	812
8	1,119	1,250	1,836	1,636	1,813	2,037	3,238	2,887
9	2,265	2,037	297	285	3,637	3,627	988	899
10	390	416	2,170	1,714	911	1,069	5,066	3,649
11		2,783	2,346			5,267	5,437	
12		4,713	796			9,013	1,002	
13		2,945	3,623			4,374	6,282	
14		4,477	1,572			7,580	2,110	
15		1,188	5,453			1,248	8,294	
16	537	299	2,632	5,754	869	512	2,509	5,506
17		3,436	3,811			4,752	4,919	
18		6,056	1,637			7,849	1,586	
19		2,719	5,521			3,608	6,243	
20		4,975	2,588			6,612	2,683	
21		1,305	7,069			1,405	7,307	
Pigeon 52								
1	1,392	1,251	1,165	1,995	3,142	2,402	2,036	3,666
2	1,525	3,322	444	493	2,707	7,280	608	561
3	909	849	1,439	2,731	1,703	1,864	2,125	5,932
4	2,993	1,616	726	745	4,624	3,935	1,354	1,096
5	566	265	1,317	2,495	920	630	2,876	7,109
6	1,917	1,863	1,840	1,997	2,862	2,897	2,503	2,839
7	1,603	1,884	451	374	4,582	5,270	831	733
8	428	485	1,414	1,153	1,462	1,539	5,111	4,120
9	1,237	1,827	643	512	3,579	5,298	924	913
10	275	315	1,811	1,399	756	829	5,509	4,750
11		2,921	2,476			5,687	5,004	
12		3,475	971			10,241	1,756	
13		1,579	2,448			3,500	6,531	
14		3,046	844			8,962	2,236	
15		665	3,272			1,092	9,315	
16	513	480	2,393	5,356	742	541	2,421	5,486
17		5,731	3,962			5,678	4,419	
18		8,416	742			9,032	727	
19		4,050	5,891			3,230	6,165	
20		7,430	2,062			7,413	1,996	
21		1,055	7,099			960	8,701	
Pigeon 53								
1	2,132	512	1,156	1,224	4,645	1,525	2,353	2,857
2	3,875	686	151	181	7,843	1,621	534	609
3	1,803	724	1,760	3,178	2,285	1,436	2,367	5,172
4	3,859	1,533	414	606	5,545	2,144	923	1,258
5	327	231	669	5,674	505	533	1,155	8,656
6	1,798	1,852	1,432	1,249	2,641	2,542	2,901	2,645
7	2,520	3,414	185	233	3,828	5,718	467	487

APPENDIX

(Extended)

Changeovers				Reinforcers			
Red		Green		Red		Green	
next R	next G	next R	next G	next R	next G	next R	next G
431	443	451	432	74	64	34	78
170	159	187	173	163	61	11	15
368	332	353	366	33	32	96	86
346	326	333	345	139	58	21	32
193	190	184	192	15	14	87	134
375	399	369	408	69	54	71	56
167	192	175	193	124	100	15	11
336	323	308	346	40	30	95	85
177	194	185	189	92	96	21	11
166	164	174	156	8	16	136	90
	526	526			113	136	
	208	209			232	18	
	535	534			85	165	
	415	418			211	39	
	219	218			19	231	
155	159	155	151	11	11	63	105
	487	484			129	121	
	282	285			222	28	
	491	494			78	172	
	419	419			194	56	
	282	281			21	229	
297	310	315	297	73	55	39	82
100	87	109	101	63	151	18	9
250	237	240	245	29	39	58	115
149	152	129	152	111	87	21	27
145	165	121	145	21	4	69	154
308	298	321	286	64	65	58	61
120	124	116	130	107	116	15	10
219	188	196	210	35	31	89	72
141	124	134	137	78	125	20	27
116	117	110	120	13	14	116	100
	404	406			124	126	
	176	181			211	33	
	328	329			73	177	
	225	229			196	45	
	125	120			19	231	
134	131	114	132	14	11	62	163
	465	462			120	130	
	95	97			227	23	
	427	427			86	164	
	262	265			195	55	
	119	116			19	231	
277	262	242	277	88	39	58	61
85	87	71	85	182	39	10	19
337	367	351	334	56	26	68	100
207	192	179	207	134	68	23	25
95	95	84	94	10	10	28	199
320	334	328	332	64	65	70	51
93	76	73	93	91	137	10	12

APPENDIX

(Continued)

Condition	Responses				Time (s)			
	Red		Green		Red		Green	
	next R	next G	next R	next G	next R	next G	next R	next G
8	861	919	2,092	2,052	1,508	1,675	3,502	3,614
9	1,834	1,708	379	331	5,126	4,452	1,117	996
10	151	122	1,847	2,182	390	345	3,911	4,508
11		3,650	3,354			5,094	5,240	
12		5,035	739			8,950	1,140	
13		2,907	3,698			3,403	5,811	
14		3,558	1,692			7,316	2,612	
15		834	4,445			1,088	7,524	
16	244	206	1,382	4,662	697	627	2,047	7,202
17		3,505	2,984			4,868	4,619	
18		4,732	704			8,882	1,085	
19		3,001	3,981			3,492	5,937	
20		4,744	1,515			7,927	2,528	
21		928	5,945			1,175	8,070	
Pigeon 54								
1	2,341	2,526	1,307	1,648	3,087	2,431	2,383	2,803
2	6,622	1,247	489	294	7,782	1,154	536	486
3	2,819	1,339	3,146	2,028	2,738	1,273	3,959	2,745
4	6,450	1,998	520	941	6,729	1,601	927	1,227
5	1,063	486	4,711	1,701	1,006	629	6,140	1,515
6	2,949	2,882	1,856	2,145	2,346	2,496	2,231	2,455
7	5,081	4,027	386	285	5,214	4,061	691	566
8	1,817	1,779	2,180	2,032	1,867	1,744	3,180	2,904
9	3,799	4,317	579	618	3,854	4,705	961	945
10	1,099	906	2,543	2,872	914	795	3,849	4,536
11		6,057	2,659			4,268	5,139	
12		5,983	943			8,095	928	
13		4,855	4,488			2,954	7,038	
14		7,432	1,242			7,653	1,953	
15		2,444	4,181			1,335	8,339	
16	1,333	1,322	6,991	918	1,042	982	6,093	1,067
17		9,943	4,781			5,687	4,315	
18		12,181	1,754			6,832	2,269	
19		5,655	6,570			3,007	6,381	
20		8,958	3,502			6,126	2,887	
21		1,880	6,732			1,395	6,767	
Pigeon 55								
1	514	1,234	961	1,700	2,084	2,841	1,942	3,819
2	503	2,795	302	438	1,932	6,320	689	1,318
3	668	433	1,455	3,354	1,670	1,136	2,575	5,267
4	3,415	2,212	376	711	5,818	2,997	896	1,768
5	393	313	1,275	3,280	830	798	2,606	5,313
6	1,431	1,399	1,416	1,463	2,776	2,748	2,512	2,629
7	2,391	3,657	160	186	4,091	6,212	357	420
8	1,135	889	1,734	2,062	2,218	1,706	3,267	3,776
9	2,166	1,852	377	352	4,224	3,450	943	971
10	267	260	1,991	2,004	700	705	4,479	4,644
11		3,315	2,936			4,921	4,848	
12		4,811	555			8,828	982	
13		2,023	3,288			3,159	6,374	
14		4,008	1,472			7,613	2,572	
15		685	5,063			1,242	9,004	
16	375	316	721	2,862	742	692	2,049	6,464

APPENDIX

(Extended)

Changeovers				Reinforcers			
Red		Green		Red		Green	
next R	next G	next R	next G	next R	next G	next R	next G
236	238	228	242	29	41	83	97
152	130	138	137	95	89	20	23
48	56	47	54	6	9	122	113
	564	566			131	119	
	179	182			217	32	
	481	481			85	165	
	384	386			199	51	
	193	190			21	229	
135	155	116	136	12	11	60	167
	499	501			123	127	
	175	177			225	25	
	464	465			76	174	
	312	312			208	42	
	175	172			26	224	
469	433	447	467	64	54	68	64
149	157	110	152	197	32	11	10
361	387	332	361	47	21	115	67
271	293	241	275	155	44	20	31
234	229	229	231	14	2	186	48
403	406	417	394	59	68	62	61
152	146	138	159	124	100	12	9
340	350	335	353	42	31	87	90
222	203	208	225	89	113	24	24
197	217	227	183	13	15	95	127
	549	548			126	124	
	192	193			226	24	
	650	648			73	177	
	375	376			205	45	
	317	318			25	225	
327	317	288	327	12	16	185	37
	692	692			136	114	
	628	630			228	22	
	573	574			77	173	
	594	595			196	54	
	321	317			31	219	
319	286	307	321	53	87	49	61
162	157	158	165	60	169	8	13
265	263	238	266	39	25	67	119
194	225	195	194	118	83	20	27
130	146	128	129	15	14	84	137
383	367	382	375	69	60	53	68
78	65	79	70	88	140	12	10
228	288	252	261	41	40	79	90
140	128	130	136	123	86	20	21
102	121	115	106	12	10	114	114
	569	569			121	129	
	159	161			227	23	
	436	436			81	169	
	439	440			197	53	
	219	217			26	224	
138	130	113	136	14	10	66	160

APPENDIX
(Continued)

Condition	Responses				Time (s)			
	Red		Green		Red		Green	
	next R	next G	next R	next G	next R	next G	next R	next G
Pigeon 56								
1	626	504	1,229	1,928	2,961	2,505	3,209	3,805
2	2,942	1,169	415	318	6,428	2,564	1,186	722
3	828	259	2,070	1,618	3,295	1,196	4,366	3,385
4	1,742	708	388	559	7,025	1,841	1,156	1,232
5	250	227	1,635	1,875	623	734	4,665	4,223
6	935	947	1,388	1,379	2,488	2,557	3,107	2,969
7	1,512	1,088	224	316	5,178	4,144	654	925
8	703	629	1,307	1,412	1,896	1,907	3,095	3,479
9	1,043	833	464	398	5,052	3,960	1,316	1,247
10	295	259	1,785	1,547	843	714	4,764	4,423
11		2,018	2,564			5,283	6,490	
12		3,192	780			8,779	1,369	
13		1,173	3,387			2,573	7,901	
14		2,726	1,160			7,092	2,541	
15		742	4,418			1,039	8,582	
16	428	438	3,374	2,411	703	523	4,553	3,847
17		4,225	2,934			4,348	4,850	
18		5,755	640			8,303	1,147	
19		3,724	4,134			3,256	6,612	
20		6,328	2,027			7,509	2,501	
21		1,367	5,403			1,532	7,991	

APPENDIX

(Extended)

Changeovers				Reinforcers			
Red		Green		Red		Green	
next R	next G	next R	next G	next R	next G	next R	next G
251	255	265	250	47	66	57	63
123	85	115	124	144	72	17	15
222	244	214	221	43	30	89	81
150	149	137	151	147	46	29	28
104	83	113	104	10	16	115	109
270	254	262	266	54	58	73	58
101	111	121	97	127	96	12	15
217	227	239	205	40	37	87	86
165	160	153	174	117	86	22	25
115	128	113	125	14	12	110	113
	469	468			130	111	
	154	153			222	26	
	320	319			69	181	
	220	223			197	53	
	184	180			28	222	
116	123	108	114	13	11	139	87
	460	464			124	126	
	189	192			231	19	
	447	444			79	171	
	388	389			204	46	
	289	286			26	224	