

*CHOICE IN A VARIABLE ENVIRONMENT: EFFECTS OF UNEQUAL  
REINFORCER DISTRIBUTIONS*

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Six pigeons were trained in a procedure in which sessions included seven unsignaled components, each offering two pecking keys, and each providing a potentially different reinforcer ratio between the two keys. Across conditions, various combinations of reinforcer ratios and reinforcer-magnitude ratios were used to create unequal reinforcer distributions between the two alternatives when averaged across a session. The results extended previous research using the same basic procedure that had included only reinforcer distributions symmetrical around 1:1. Data analyses suggested that the variables controlling choice operated at a number of levels: First, individual reinforcers had local effects on choice; second, sequences of successive reinforcers obtained at the same alternative (continuations) had cumulative effects; and, third, when these sequences themselves occurred with greater frequency, their effects further cumulated. A reinforcer obtained at the other alternative following a sequence of continuations (a discontinuation) had a large effect and apparently reset choice to levels approximating the sessional reinforcer ratio.

*Key words:* concurrent schedules, choice, reinforcer-ratio variation, reinforcer sequences, generalized matching, key peck, pigeons

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In the experimental analysis of behavior, much research has focused on the quantification of steady-state choice in concurrent schedules. In particular, the generalized matching law (Baum, 1974) has been used to describe choice in a variety of procedures and species (see Davison & McCarthy, 1988, for a review). This law has been influential both in terms of how behavior is viewed and in how data are collected and examined.

More recently, experimenters have begun examining choice in conditions that change more frequently than in studies of steady-state behavior. Mazur and colleagues (Bailey & Mazur, 1990; Mazur, 1992, 1995, 1996, 1997; Mazur & Ratti, 1991) investigated the effects of a single within-session change in the reinforcer ratio available from two alternatives. Another approach used pseudorandom binary

sequences to change reinforcer ratios unpredictably from session to session (Hunter & Davison, 1985; Schofield & Davison, 1997). Both approaches have shown that previous reinforcer ratios affect current performance to some degree.

Davison and Baum (2000) reported a study in which they used a procedure introduced by Belke and Heyman (1994) to study choice in conditions that changed even more frequently. Seven different reinforcer ratios (27:1, 9:1, 3:1, 1:1, 1:3, 1:9, and 1:27) were presented to the subjects in a random order in each session. Each of these seven components was separated by a 10-s blackout of the keylights. Component length was varied across conditions from four to twelve reinforcers, and the overall rate of reinforcement was varied over two levels.

Davison and Baum (2000) showed that choice changed very rapidly, with log response ratios adjusting quickly as successive reinforcers were obtained in a component. Using multiple linear regressions, they showed that sensitivity to the reinforcer ratio in the current component leveled off at moderately high levels (0.6 to 0.8) after about eight reinforcer deliveries. Sensitivity to the previous-component reinforcer ratio started at about 0.2 to 0.3 and then decreased with successive reinforcers obtained in the current component but was still generally positive after five or six reinforcer deliveries. Davison

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and Baum found no evidence that component length affected the speed with which behavior changed. They did, however, find that sensitivity to reinforcer ratios increased more rapidly, and reached higher levels, when the overall reinforcer rate was higher.

At a more local level of analysis, Davison and Baum (2000) showed that each individual reinforcer had a reliable effect on behavior. Within components, each successive reinforcer obtained at the same alternative (hereafter to be called a *continuation*) had a decreasing effect on subsequent choice. But a single reinforcer obtained from the other alternative (to be called a *discontinuation*) following a sequence of continuations always had a comparatively large effect. Davison and Baum concluded that these strong regularities of reinforcers at a reinforcer-by-reinforcer level of analysis suggested that choice was controlled at a local level.

Davison and Baum (2002) reported further research using the same procedure. Components were either four or ten reinforcers in length, and blackout duration between components was varied from 1 s to 120 s. The amount of control exerted by the previous-component reinforcer ratio decreased as the duration of the blackout was increased. An even more local analysis showed a movement in choice towards the just-reinforced response (a "choice pulse") following a reinforcer delivery. Following the choice pulse, choice became less extreme as the time since the reinforcer delivery increased.

Davison and Baum (2002) reasoned that the choice changes evident between reinforcer deliveries might be the same as the choice changes that appeared to occur during the blackouts between components. To examine this, they arranged two conditions that contained 60-s blackout between components and two additional conditions with 60-s periods of unsignaled extinction between components. Choice fell towards indifference during extinction and reached similar levels following both 60-s extinction and 60-s blackout between components.

Landon and Davison (2001) examined the effects on choice of the range of within-session reinforcer-ratio changes using the same basic procedure. In their first experiment, they found that choice became more extreme in response to the same sequences of rein-

forcers when a greater range of reinforcer ratios was arranged. Moreover, sensitivity reached higher levels when the range was greater. Similar local effects of reinforcers to those reported by Davison and Baum (2000, 2002) were evident, with continuations having decreasing effects on choice, and discontinuations having larger effects on choice.

Landon and Davison's (2001) results suggested the presence of both local and longer-term control over responding. The effects of a particular reinforcer were modulated by several factors: The alternative from which the reinforcer was obtained, the sequential position in a component at which the reinforcer was obtained, the particular sequence of reinforcers preceding that reinforcer, and the distribution of arranged reinforcer ratios across components.

Landon, Davison, and Elliffe (2002) generalized many of these findings to a steady-state concurrent-schedule procedure. They showed that previously obtained reinforcers contributed to current choice, but that the largest contribution was from the most recently obtained reinforcer. Following a reinforcer delivery, there was a large choice pulse towards the just-reinforced response. Thereafter choice returned to a stable level that remained unchanged even during unusually long interreinforcer intervals. These stable choice levels varied as a function of the reinforcer ratio arranged in each condition and were not simply movements towards indifference as reported by Davison and Baum (2002). Landon *et al.*'s results therefore suggested that choice was controlled by both short- and long-term aggregations of reinforcers.

That both short- and longer-term aggregations of reinforcers exert some control over choice has been evident in procedures in which the reinforcement contingencies change rapidly (Landon & Davison, 2001) and in a more standard, steady-state, arrangement (Landon *et al.*, 2002). One difference between these procedures, however, warrants investigation. Previous research using Belke and Heyman's (1994) procedure (Davison & Baum, 2000, 2002; Landon & Davison, 2001) used reinforcer ratio distributions symmetrical around 1:1. Thus in every condition arranged in these studies approximately equal numbers of reinforcers were obtained for re-

sponding to each of the two alternatives across each session. In contrast, in the conventional steady-state procedure (Landon et al., 2002), this was only the case when the reinforcer ratio was 1:1. It is possible, therefore, that the movements in choice during both interreinforcer intervals and periods of un signaled extinction observed by Davison and Baum (2002) represent movements towards a long-term aggregated reinforcer ratio of unity, rather than simple movements towards indifference.

To examine this further, the present experiment used Belke and Heyman's (1994) procedure and arranged various unequal reinforcer distributions to examine how these distributions affected choice within components. In Conditions 1 through 4, the range of reinforcer ratios used by Davison and Baum (2000; i.e., 27:1 to 1:27, spaced in equal logarithmic steps) was shifted so that it was centered at 3:1 (i.e., 81:1 to 1:9) or 1:3 (9:1 to 1:81). Different conditions arranged blackouts between components of either 1 s, 10 s, or 120 s in duration. In Conditions 5 and 6, the reinforcer-magnitude ratios were made unequal (3:1 and 1:3, respectively) with the component reinforcer ratios varying from 27:1 to 1:27. In Conditions 7 and 8, narrower ranges of reinforcer ratios were arranged, centered on 1:8 and 8:1. Finally, in Conditions 9 through 12, the reinforcer ratios did not change within sessions. In these conditions, sessions were constructed in the same manner (i.e., successive components separated by 10-s blackouts), but all components contained the same reinforcer ratio (8:1, 1:8, 4:1, and 1:4, respectively). Thus these last four conditions were functionally equivalent to steady-state concurrent schedules (Landon et al., 2002).

## METHOD

### *Subjects*

The subjects were the same 6 homing pigeons numbered 61 to 66 used by Landon and Davison (2001). All subjects except Pigeon 64 were maintained at  $85\% \pm 15\%$  of their free-feeding body weights. It was impossible to maintain Pigeon 64 at this level of deprivation given the number of reinforcers arranged per session, so its target weight was

changed to  $90\% \pm 15\%$  of its free-feeding weight. The subjects were maintained at their designated body weights by supplementary feedings of mixed grain a few hours after the daily training sessions. The experimental room was lit from 1:00 a.m. to 4:00 p.m., and sessions were conducted pigeon by pigeon beginning at 1:30 a.m.. Water and grit were freely available to the subjects at all times.

### *Apparatus*

Each pigeon was housed in a cage 380 mm high, 380 mm wide, and 380 mm deep. The back, left, and right walls of each cage were constructed of sheet metal, whereas the top, floor, and front wall consisted of metal bars. Each cage contained two wooden perches mounted 50 mm from the chamber floor. One was mounted 95 mm from, and parallel to, the front wall, and the second was mounted 95 mm from, and parallel to, the right wall. Illumination was provided by the ambient room lighting, and there was no sound attenuation.

The right wall of each cage contained three translucent response keys, 20 mm in diameter, centered 100 mm apart, and 200 mm above the perches. The center key was always dark and inoperative. The two side keys could be transilluminated yellow and, when lit, operated by pecks exceeding a force of about 0.10 N. A hopper containing wheat was located behind an aperture (50 mm by 50 mm) situated 145 mm below the center key. During reinforcer delivery, the hopper was raised and illuminated for 2.5 s (except for the conditions in which reinforcer magnitude was changed, described below) and the keylights extinguished. From the home cages, other pigeons participating in other experiments were visible and audible, but no personnel entered the room while the experiments were running. All experimental events were arranged on an IBM®-PC compatible computer running MED-PC® software, situated remote from the experimental cages. The computer also recorded, to 10 ms resolution, the time at which every experimental event occurred.

### *Procedure*

The subjects were trained on the same two-key concurrent schedule procedure used by Landon and Davison (2001). Sessions began with both side keys lit yellow. Once 10 rein-

Table 1

Sequence of experimental conditions showing each of the component reinforcer ratios and the duration of the blackouts between components in each condition. The overall probability of reinforcement per second was constant at .037 throughout. Reinforcement consisted of 2.5-s access to wheat, except in Conditions 5 and 6 in which reinforcer magnitudes were 6:2 and 2:5, respectively (arranged using successive 1.2-s hopper presentations).

Condition	Component reinforcer ratios (L:R)	Blackout between component (s)
1	1:81, 1:27, 1:9, 1:3, 1:1, 9:1	10
2	1:9, 1:3, 1:1, 3:1, 9:1, 27:1, 81:1	10
3	1:9, 1:3, 1:1, 3:1, 9:1, 27:1, 81:1	1
4	1:9, 1:3, 1:1, 3:1, 9:1, 27:1, 81:1	120
5	1:27, 1:9, 1:3, 1:1, 3:1, 9:1, 27:1	10
6	1:27, 1:9, 1:3, 1:1, 3:1, 9:1, 27:1	10
7	1:27, 1:18, 1:12, 1:8, 1:5.33, 1:3.56, 1:2.37	10
8	2.37:1, 3.56:1, 5.33:1, 8:1, 12:1, 18:1, 27:1	10
9	ALL 8:1	10
10	ALL 1:8	10
11	ALL 4:1	10
12	ALL 1:4	10

forcers had been obtained, both keylights were extinguished and a 10-s blackout began. After the blackout, the next component began with the side keys again lit yellow. Sessions were conducted daily and ended in blackout after seven components or 45 min, whichever occurred first.

Before the beginning of each component, the computer selected the next component randomly without replacement from a list (Table 1). Consequently, subjects were exposed to seven, sometimes different, pairs of concurrent variable-interval (VI) schedules during each session. Reinforcers were scheduled using a single exponential VI 27-s schedule ( $p = .037/s$ ). Once a reinforcer was arranged, it was allocated to one of the alternatives according to the probability selected for that component. Reinforcers were dependently scheduled (Stubbs & Pliskoff, 1969), so that once a reinforcer was arranged for one alternative, no further reinforcers were arranged until that reinforcer had been obtained. A 2-s changeover delay (Herrstein, 1961) prevented responses from producing an arranged reinforcer until 2 s had elapsed since the first response at that alternative following a response at the other alternative.

The procedure was altered for Conditions 3 through 6 in the following ways. Condition 3 arranged a 1-s blackout between components, and Condition 4 arranged a 120-s blackout. The long blackouts in Condition 4

necessitated an increase in the maximum session duration to 60 min for that condition. In Conditions 5 and 6, the magnitude of reinforcement was unequal; a 6:2 Left/Right (L/R) ratio was arranged in Condition 5 and a 2:6 ratio in Condition 6. This was arranged as follows: For these conditions, reinforcers consisted of successive 1.2-s hopper presentations in the manner of Davison and Baum (2003). These presentations were separated by 0.5-s blackouts. Thus, in Condition 5, a left-alternative reinforcer consisted of six successive 1.2-s hopper presentations, and a right-alternative reinforcer consisted of two successive 1.2-s hopper presentations. These were reversed in Condition 6.

The sequence of experimental conditions is shown in Table 1. In Conditions 1 and 2, the range of reinforcer ratios was held constant (9:1 to 81:1 and 81:1 to 1:9, respectively). Conditions 3 and 4 used the same range of reinforcer ratios as Condition 2 (81:1 to 1:9), with blackouts between components of 1 s and 120 s, respectively. The range of reinforcer ratios arranged in Conditions 5 and 6 was constant at 27:1 to 1:27, and the ratio of reinforcer magnitudes was varied (3:1 and 1:3, respectively). For Conditions 7 and 8, the range was narrowed (27:1 to 2.37:1 and 1:2.37 to 1:27), and centered on reinforcer ratios of 1:8 and 8:1 respectively. Finally, in Conditions 9 through 12, each of the seven components in a session arranged the same

reinforcer ratio (8:1, 1:8, 4:1, and 1:4 respectively).

## RESULTS

Davison and Baum (2000) used multiple linear regressions to assess the linear contributions of the reinforcer ratio in the current component (current-component sensitivity) and in the previous component (previous-component sensitivity) on performance before each reinforcer delivery in the current component. The equation for this analysis is

$$\log\left(\frac{B_{ln}}{B_{rn}}\right) = a_{pn}\log\left(\frac{R_{lp}}{R_{rp}}\right) + a_{cn}\log\left(\frac{R_{lc}}{R_{rc}}\right) + \log c, \quad (1)$$

where  $B$  refers to responses emitted and  $R$  refers to reinforcers obtained. The subscripts  $l$  and  $r$  refer to the left and right alternatives,  $p$  and  $c$  refer to the previous and current components, and  $n$  refers to the reinforcer number in a component.

For Conditions 1 through 8, which arranged within-session variation of the reinforcer ratios, the numbers of responses emitted at each alternative were summed in each successive interreinforcer interval according to the identities of both the current and previous components. Equation 1 was then fitted to the data by least-squares multiple linear regression. Figure 1 shows sensitivity to the current- and previous-component reinforcer ratios plotted as a function of successive reinforcer deliveries in a component for Conditions 1 through 8 for each subject individually and for the group (the raw data summed across subjects).

Because subsequent analyses will present only group data, it is important to consider whether the group data accurately represent the major features of the individual data. Figure 1 shows that this is the case. Although group values of sensitivity to the current-component reinforcer ratio were lower than most of the individual values, this simply represents the effect, in the individual data, of low response counts in some components producing relatively extreme response ratios and therefore higher estimates of sensitivity. This

effect is eliminated when data are summed across subjects.

In Conditions 7 and 8, both the group and individual data were more variable than in other conditions. This might be because these conditions arranged a smaller range of within-session changes in log reinforcer ratios (see Landon & Davison, 2001). Alternatively, it could be because there was no reversal in the reinforcer ratios across components.

Figure 1 shows the same patterns of change in sensitivity in all conditions, whether individual or group data are considered, and despite the greater variability in Conditions 7 and 8. Sensitivity to the previous-component reinforcer ratio started above zero and then fell towards zero with successive reinforcer deliveries. In contrast, sensitivity to the current-component reinforcer ratio began close to zero and generally increased with successive reinforcer deliveries.

Figure 1 appears to show effects of varying the blackout duration in Conditions 2, 3, and 4 on control by both the previous- and current-component reinforcer ratios. That is, as blackout duration was increased, control by the previous-component reinforcer ratio decreased, and sensitivity to the current-component reinforcer ratio increased. Such effects are consistent with those reported by Davison and Baum (2002). To investigate this more closely, separate two-way repeated measures analyses of variance (ANOVAs) using sensitivity to the current- and previous-component reinforcer ratios were used. The first ANOVA was performed on the individual-subject values of sensitivity to the current-component reinforcer ratio. Sensitivity values measured before any reinforcers were obtained were omitted, and the ANOVA showed significant effects of both blackout duration ( $F_{1,80} = 4.90, p < .05$ ), the sequential position of the reinforcer ( $F_{7,80} = 4.39, p < .05$ ), and that interactions were not significant ( $F_{7,80} = 0.01, p > .05$ ). The second ANOVA examined the individual-subject values of sensitivity to the previous-component reinforcer ratios, including the values calculated before any reinforcers were obtained in a component. In contrast to the more extensive investigation reported by Davison and Baum, there was no significant effect of blackout duration ( $F_{1,90} = 2.70, p > .05$ ). There was a significant effect of the sequential position of

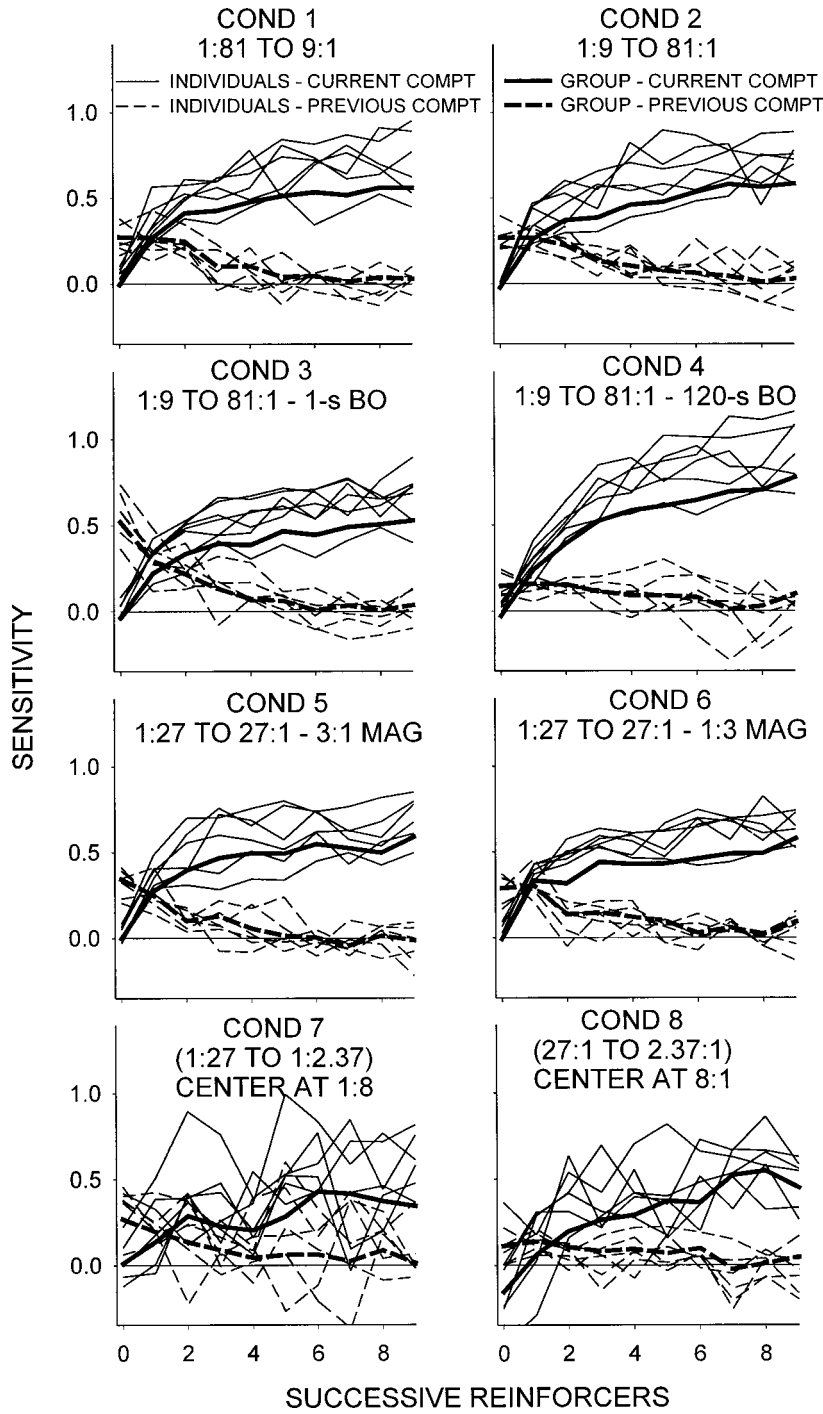


Fig. 1. Sensitivity to reinforcer ratio from multiple linear regressions between log response ratios and arranged log reinforcer ratios (Equation 1) in the previous and current components for each successive reinforcer delivery. Each panel represents data from a different condition. The data for each pigeon are shown, and the bold lines show the group data for which response numbers were summed across all 6 pigeons.

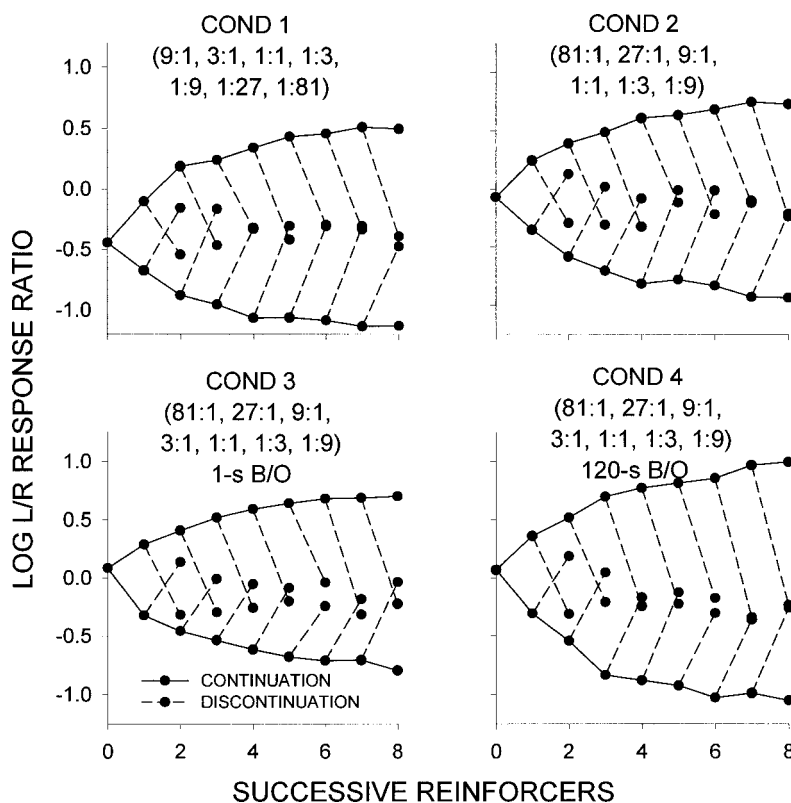


Fig. 2. Log response ratios in interreinforcer intervals following successive same-alternative reinforcers (continuations; solid lines) in Conditions 1 through 4. The broken lines represent discontinuations, reinforcers obtained from the other alternative following sequences of successive continuations.

the reinforcer ( $F_{8,90} = 13.12$ ,  $p < .05$ ), and interactions were not significant ( $F_{8,90} = 1.31$ ,  $p > .05$ ).

The reinforcer-by-reinforcer analysis first reported by Davison and Baum (2000) was used to examine the effects of successive individual reinforcers on choice. Log response ratios were calculated separately for interreinforcer intervals following all possible sequences of reinforcers obtained from the beginning of a component. Figure 2 shows part of the resulting tree structures from these analyses for Conditions 1 (9:1 to 1:81) and 2 through 4 (81:1 to 1:9, with 10, 1, and 120-s blackouts between components, respectively). Sequences of successive reinforcers obtained at the same alternative (continuations) are shown, as are reinforcers obtained at the other alternative following a sequence of successive continuations (discontinuations; Davison & Baum, 2003). The trees are similar to those reported previously (Davison & Baum, 2003;

Landon & Davison, 2001): Successive continuing reinforcers had diminishing effects on choice, discontinuations had comparatively large effects on choice, and discontinuations early in a component resulted in reversals of choice.

The trees also differ in a number of ways from those reported earlier by Davison and Baum (2000) and Landon and Davison (2001). First, choice before any reinforcer deliveries in a component was influenced by the sessional reinforcer ratios arranged—in Condition 1 (mean overall log reinforcer ratio =  $-0.48$ ), the log response ratio emitted before any reinforcers were obtained was  $-0.45$ , whereas in Condition 2 (mean overall log reinforcer ratio =  $0.48$ ), it was  $-0.07$ . Although this was a substantial movement in choice, choice did not reverse fully. The difference between the two initial response ratios suggests an overall position bias in favor of the right key of about  $-0.26$ , consistent with ear-

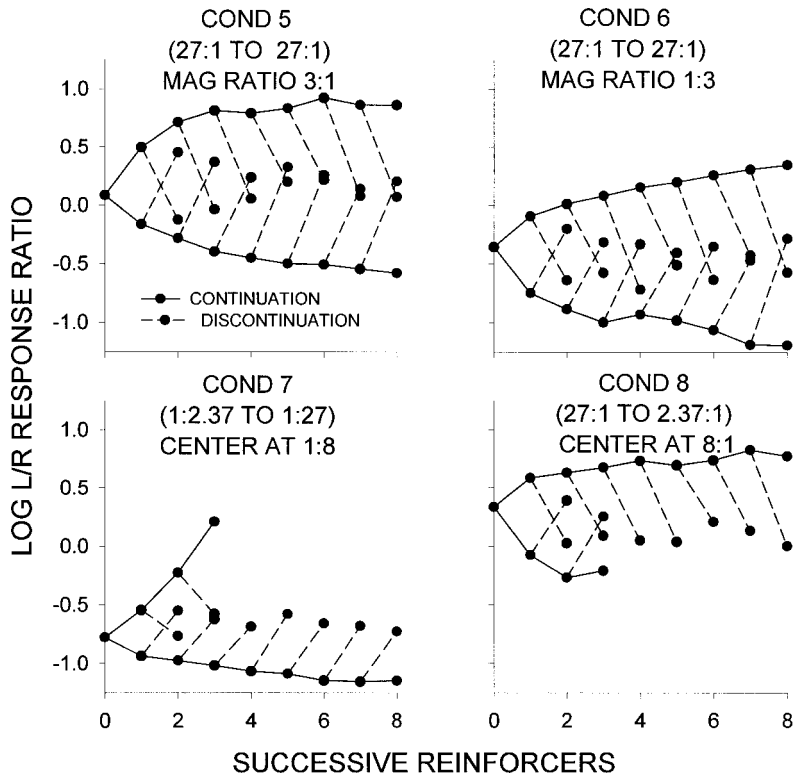


Fig. 3. Log response ratios in interreinforcer intervals following successive same-alternative reinforcers (continuations; solid lines) in Conditions 5 through 8. The broken lines represent discontinuations, reinforcers obtained from the other alternative following sequences of successive continuations.

lier data obtained from the same subjects by Landon and Davison. Conditions 3 and 4 arranged the same log reinforcer ratios as did Condition 2. In Condition 3 (1-s blackout between components), choice before any reinforcers were obtained moved towards the left alternative (0.08) suggesting an effect of the shortened blackout. In Condition 4 (120-s blackout), however, this initial choice did not change (0.07). This inconsistent effect of blackout duration would be expected if initial choice in a component were determined by the extended average reinforcer ratio (which remained unchanged for three successive conditions) to a greater extent than by the blackout between components.

Second, the trees were, in all four conditions, asymmetrical. Arranging unequal distributions of component reinforcer ratios always produced a shift in choice towards the overall higher-rate alternative, adding to or subtracting from the overall bias towards the right key noted above. As a component pro-

gressed, reinforcers obtained at the overall higher-rate alternative had smaller, and diminishing, effects on subsequent choice than did reinforcers obtained at the overall lower-rate alternative, resulting in a shallower curve for the higher-rate alternative.

Figures 3 and 4 show that Conditions 5 through 8 and 9 through 11 produced similar results. In Conditions 5 and 6, which arranged unequal reinforcer magnitudes, the tree structures as a whole shifted towards the alternative providing larger reinforcers and were again asymmetrical. Successive reinforcers obtained at the alternative providing larger reinforcers had smaller effects than did those obtained at the other alternative, resulting in a shallower curve for the smaller-magnitude alternative. Discontinuations had effects similar to those seen previously.

In Conditions 7 and 8, the range of reinforcer ratios was narrowed (1:2.37 to 1:27 and 27:1 to 2.37:1) and centered on 1:8 and 8:1, respectively. Figure 3 shows that the tree



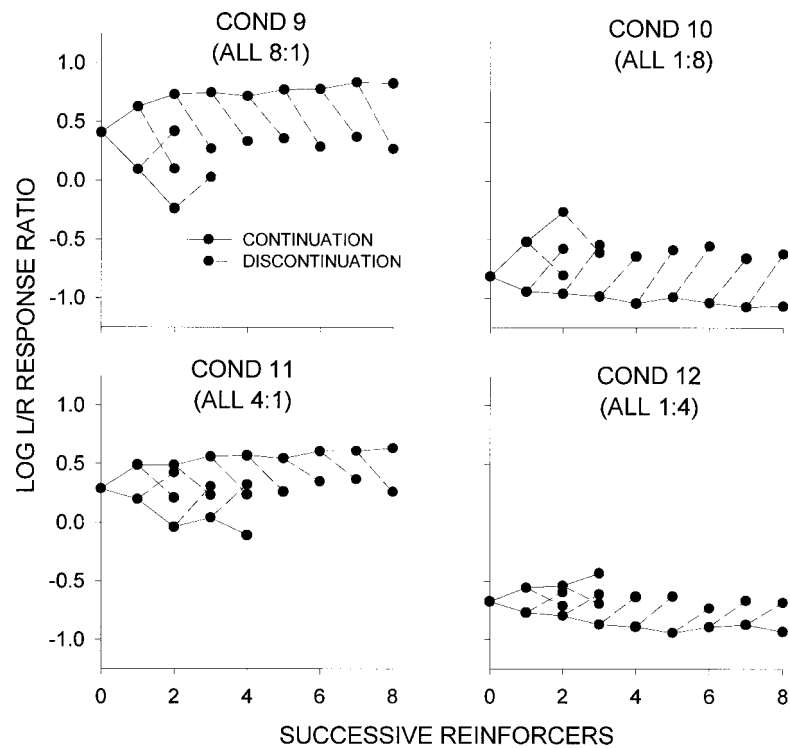


Fig. 4. Log response ratios in interreinforcer intervals following successive same-alternative reinforcers (continuations; solid lines) in Conditions 9 through 12. The broken lines represent discontinuations, reinforcers obtained from the other alternative following sequences of successive continuations.

structures were strongly biased towards the higher-reinforcer-rate alternative. Successive reinforcers obtained at the right alternative in Condition 7, and at the left alternative in Condition 8 (continuations), had small effects on choice. These small effects suggest that there are limits to how far choice will move towards the high-reinforcer-rate alternative given a particular distribution of reinforcer ratios. Discontinuations at the lower-reinforcer-rate alternative consistently moved choice beyond the average level seen before any reinforcer deliveries in a component. Although a second or third successive reinforcer on the lower-rate alternative sometimes had a large effect, the sample sizes associated with these estimates were small, making them possibly unreliable.

In each of Conditions 9 through 12 (Figure 4), all seven components in a session arranged the same reinforcer ratio. Thus these conditions were steady-state concurrent schedules with blackouts after every 10 reinforcer deliveries. Figure 4 shows that the re-

sults from Conditions 9 and 10 (constant 8:1 and 1:8 reinforcer ratios) resembled those from Conditions 7 and 8 (average 8:1 and 1:8 reinforcer ratios). The tree structures were again asymmetrical, with the trees biased towards the higher-reinforcer-rate alternative. These changes in the tree structures were ordered in the same way as the reinforcer ratios. Successive reinforcers at the higher-reinforcer-rate alternative had small effects on choice. Figure 4 again suggests that in each condition there may be a limit on how far choice moves following successive reinforcers obtained at that alternative. Discontinuations again had comparatively large effects on choice. In Conditions 9 and 12, discontinuations at the lower-reinforcer-rate alternative moved choice beyond the level seen before a reinforcer delivery in a component; in Conditions 10 and 11 they moved choice to similar levels to those before any reinforcer deliveries.

Conditions 7 and 10 and Conditions 8 and 9 arranged the same sessional reinforcer ra-

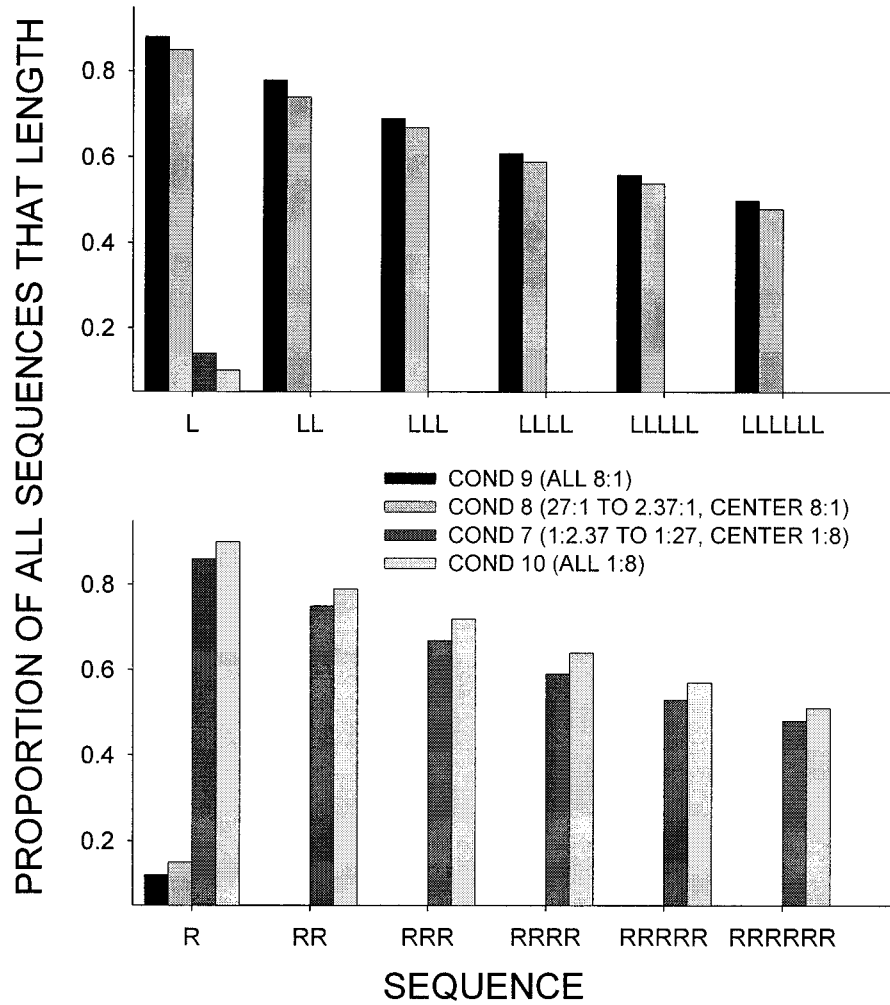


Fig. 5. The proportions of all sequences two to six reinforcers in length that consisted exclusively of successive reinforcers at one alternative for Conditions 7, 8, 9, and 10. L and R stand for reinforcers obtained from the left and right keys.

tios (1:8 and 8:1, respectively), but differed in terms of whether a range of reinforcer ratios was distributed around this sessional average (see Table 1). Comparisons of these pairs of conditions showed almost identical results at this level of analysis (Figures 3 and 4). Within each pair of conditions, choices were similar at the beginning of a component and continued to be similar throughout a component following various specific sequences of reinforcers.

The next analysis examines how the frequency of particular sequences of reinforcers obtained was affected by arranging either a single sessional reinforcer ratio (Conditions 9

and 10) or a range of component reinforcer ratios centered on those sessional ratios (Conditions 7 and 8). Figure 5 shows the proportions of total obtained sequences of reinforcers that were exclusively successive continuations (e.g., all left-alternative reinforcers) for sequence lengths from 2 to 6 reinforcers. Conditions 9 and 8 and Conditions 7 and 10, respectively, resulted in similar proportions of sequences that were exclusively continuations. Despite this, they did differ in small but systematic amounts. For example, Conditions 9 and 8 both resulted in high percentages of components beginning with six successive left reinforcers, but for Condition

9 (fixed reinforcer ratio of 8:1) this was 50% whereas for Condition 8 it was 48%. This difference was consistent throughout, with Condition 9 always producing a slightly higher percentage of these sequences. Conditions 7 and 10 produced analogous differences, showing a consistently higher percentage of all-right sequences for the fixed reinforcer ratio (Condition 10). Other sequences (including those not shown) occurred infrequently, and those that occurred more frequently contained a large proportion of left reinforcers in Conditions 8 and 9 (right reinforcers in Conditions 7 and 10), but few differences were evident across conditions (e.g., LLLLLR, 6% in both Conditions 8 and 9, and RLLLLL, 8% in both conditions).

An even more local analysis was used to examine the changes in choice during interreinforcer intervals following specific sequences of reinforcers. Responses in the interreinforcer intervals after each possible sequence of reinforcers obtained from the beginning of a component were collated. These were then used to calculate log response ratios in successive 2-s bins within those interreinforcer intervals.

Figure 6 shows the log left/right response ratios in successive 2-s time bins by Pigeons 61 and 65 in Conditions 2 (81:1 to 1:9), 11 (all 4:1), 8 (27:1 to 2.37:1), and 9 (all 8:1). These 2 pigeons' performances were representative of performances of all pigeons. The conditions shown are representative of the other conditions, and were chosen simply because they all contain reinforcer-ratio distributions that favored the left alternative. Responding in a time bin was sometimes exclusively to the alternative from which a reinforcer was just obtained. These occurrences have been denoted by inverted triangles. Data points have also been omitted when a particular time bin was reached on fewer than 20 occasions, and log response-ratios obtained more than 40 s after the previous reinforcer are not shown.

Figure 6 shows that each reinforcer delivery was followed by a large pulse in choice towards the just-reinforced response. Choice then became less extreme and apparently stabilized after ten to fifteen 2-s bins. Figure 6 shows several differences across conditions and across successive continuations in the levels at which choice became stable for Pigeons 61 and 65.

In Condition 2 (81:1 to 1:9), choice increasingly favored the left alternative as successive left-alternative continuations accumulated. Choice also shifted towards the right alternative when successive right-alternative continuations were obtained. The other three conditions showed little evidence that choice was changing in this way across successive continuations.

Figure 7 shows the same data summed across all pigeons. First, the effects noted in Figure 6 are clear in these group data, demonstrating again the group data were representative of the individual-pigeon data. Choice pulses were present after each reinforcer delivery, and choice became reasonably stable ten to fifteen 2-s bins after a reinforcer delivery. Increments in these stable levels of choice with successive left- or right-alternative continuations were evident in Condition 2 (81:1 to 1:9). These increments were also evident, although to a lesser extent, following successive left-alternative continuations in Condition 8 (27:1 to 2.37:1). No such changes occurred in Conditions 11 (4:1) or 9 (8:1), although the stable levels in Condition 9 were consistently more extreme than those in Condition 11.

Figures 6 and 7 suggest that choice in the last five 2-s bins (i.e., more than 30 s after the preceding reinforcer) may be taken as stable. Figure 8 shows the mean log response ratio obtained more than 30 s after the last reinforcer of sequences of successive left-alternative reinforcers. The upper panel shows Conditions 2, 3, and 4, in which the range of reinforcer ratios was constant (81:1 to 1:9) and the blackout between components varied (10, 1, and 120 s, respectively). Choice became more extreme as successive continuations were obtained. Moreover, from the third reinforcer onwards choice was strictly ordered according to the length of the blackout.

The central panel in Figure 8 shows the equivalent data from Conditions 5 and 6 (6:2 and 2:6 reinforcer magnitude ratios, respectively). Choice generally moved towards the left alternative, by approximately the same amount, as successive left-alternative reinforcers were obtained. The separation between the functions for each condition measures the effects of arranging unequal reinforcer magnitudes. Because the two func-

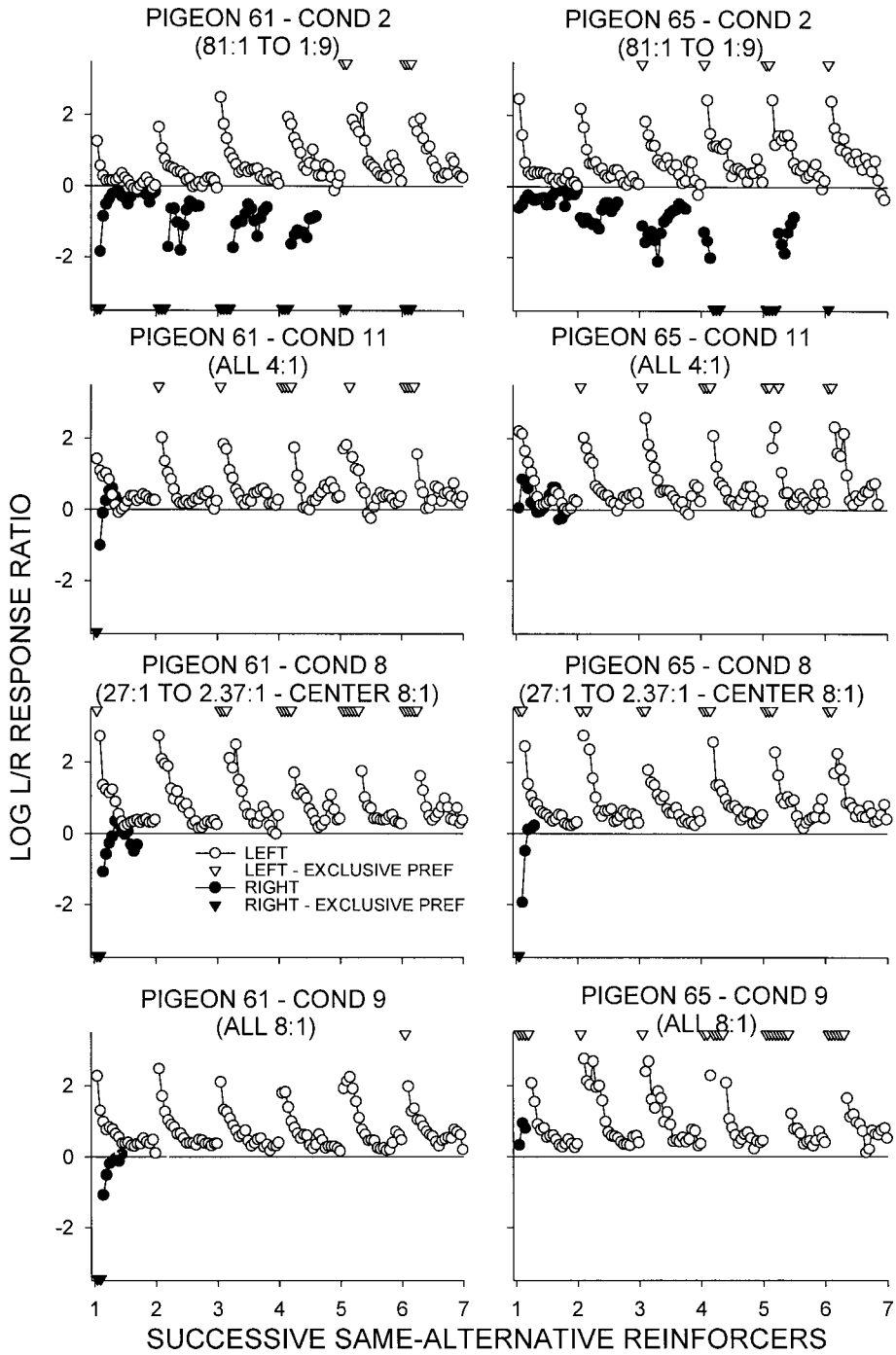


Fig. 6. The log response ratios in successive 2-s time bins in Conditions 2, 8, 9, and 11 for Pigeons 61 and 65 following sequences of successive same-alternative reinforcers obtained from the start of a component. Data were omitted when a particular time bin was reached on fewer than 20 occasions. The triangles denote occasions when choice was exclusive to one alternative.

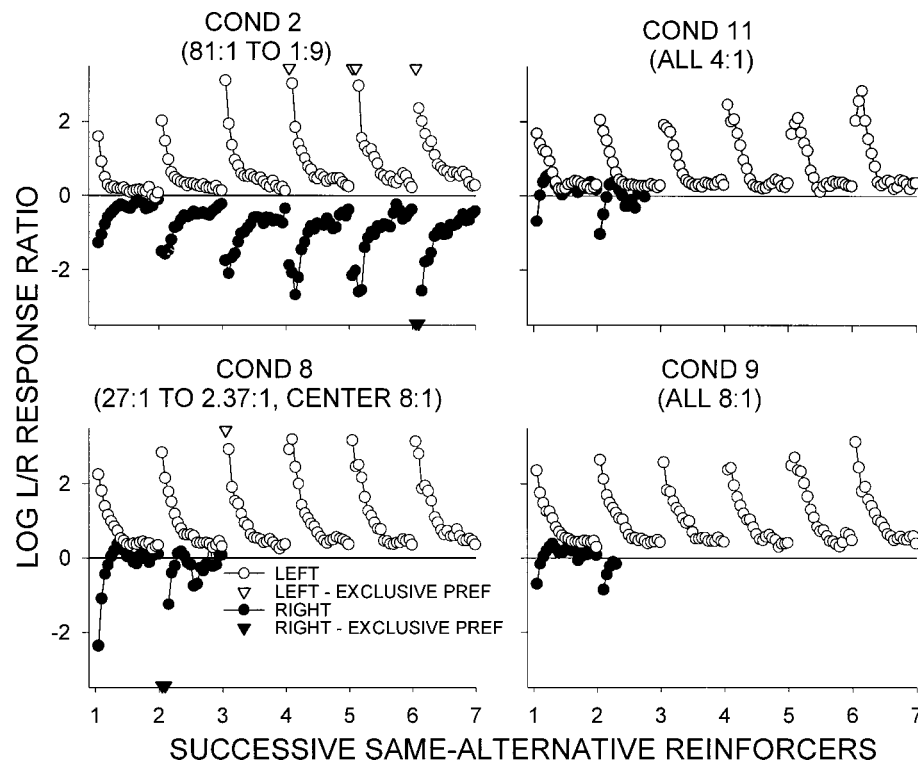


Fig. 7. The log response ratios in successive 2-s time bins in Conditions 2, 8, 9, and 11 following sequences of successive same-alternative reinforcers obtained from the start of a component. Data were omitted when a particular time bin was reached on fewer than 20 occasions. The triangles denote occasions when choice was exclusive to one alternative.

tions are parallel, the effect of reinforcer magnitude remained constant throughout a component. To confirm this, straight lines (not shown) were fitted to each function by least-squares regression. Almost identical slopes (0.07 and 0.05 for Conditions 5 and 6, respectively) were produced, showing that the effect on stable choice of continued sequences of left-alternative reinforcers was not influenced by the relative magnitude of those reinforcers.

The bottom panel in Figure 8 shows data from Conditions 11 (all 4:1), 8 (27:1 to 2.37:1), and 9 (all 8:1). Comparison of Conditions 11 and 9, in which a single reinforcer ratio was arranged in every component, reveals that log response ratios favored the left alternative more when left-alternative reinforcers were more frequent (Condition 9). In all three conditions, choice moved only slightly towards the left alternative with each successive left-alternative reinforcer.

Figure 9 shows choice in successive 2-s bins

following sequences of continuations that ended with a single discontinuation. As in Figures 6 and 7, these data are shown for Conditions 2 (81:1 to 1:9), 11 (all 4:1), 8 (27:1 to 2.37:1), and 9 (all 8:1). The leftmost choice pulses, following a single left- or right-alternative reinforcer, are identical to those shown in Figure 7. Figure 9 shows that within each condition, choice was reasonably similar across discontinuations after a series of same-alternative reinforcers. The choice pulses were much shorter than those following a continuation (cf., Figure 7), even when the discontinuation was obtained at the richer of the two alternatives (see the open circles for Condition 2).

## DISCUSSION

The present results replicated those reported previously (Davison & Baum, 2000, 2002; Landon & Davison, 2001) at a number of levels. The control exerted by the current-

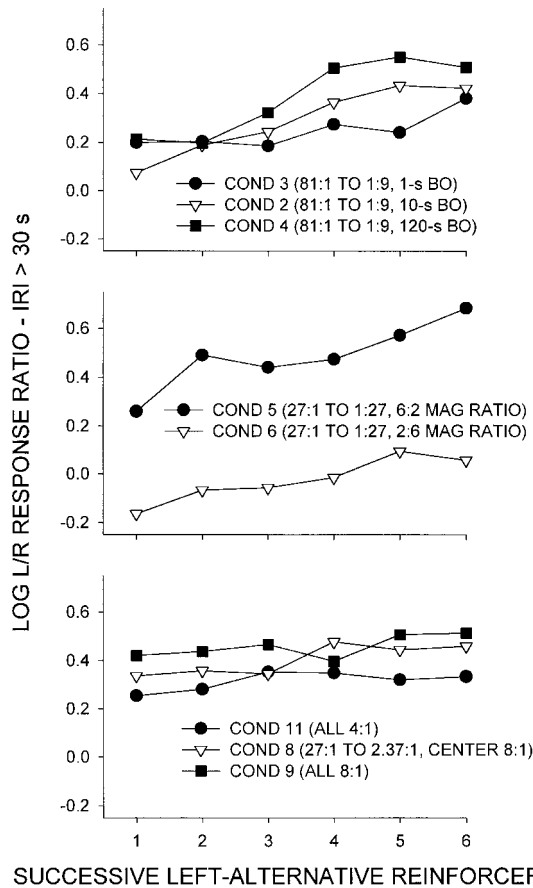


Fig. 8. The log response ratios in interreinforcer intervals that exceeded 30 s following sequences of successive left-alternative reinforcers plotted as a function of the sequence length for Conditions 2, 3, 4, 5, 6, 8, 9, and 11.

and previous-component reinforcer ratios was similar to that seen previously. Control by the previous-component reinforcer ratio carried over into the current component, and decreased with successive reinforcers in that component (Figure 1). Conditions 7 (1:2.37 to 1:27) and 8 (27:1 to 2.37:1) yielded lower, and more variable, values of sensitivity to the current-component reinforcer ratio than other conditions in the present study. This result is consistent with that reported by Landon and Davison, who showed that lower sensitivity values were obtained when the range of within-session reinforcer ratios was smaller. The increased variability in sensitivity values were likely to have resulted from the smaller range of reinforcer ratios arranged (*cf.*, Landon & Davison), and more particularly from

the absence of reversals of the rich alternative in these conditions.

The within-component reinforcer-by-reinforcer analyses (Figures 2, 3, and 4) also replicated the main effects seen previously. Successive continuing reinforcers had diminishing effects. In contrast, discontinuations had comparatively large effects (Davison & Baum, 2000, 2002; Landon & Davison, 2001). The unequal distributions of reinforcers arranged in the present experiment, however, did result in differences at this level of analysis. First, the tree structures as a whole moved towards the higher reinforcer-rate (or larger-magnitude) alternative. Second, the tree structures became noticeably asymmetrical, with choice at the start of a component favoring the higher reinforcer-rate (or larger-magnitude) alternative and subsequent reinforcers from that alternative having small diminishing effects. In contrast, successive reinforcers at the lower reinforcer-rate (or smaller-magnitude) alternative had larger diminishing effects.

Analyses of choice during interreinforcer intervals were informative on how the within-component reinforcer-by-reinforcer results arose. Figures 6 through 9 show that a reinforcer was followed by a choice pulse towards the alternative from which the reinforcer was obtained. Figures 6 and 7 show that reinforcers in a sequence of successive same-alternative reinforcers had cumulating effects on choice following the choice pulses. Increments in choice were particularly evident when a distribution of reinforcer ratios was arranged that contained reversals (*e.g.*, Condition 2 in Figure 7). When no reversals were arranged (*e.g.*, Conditions 8, 9, and 11), choice pulses remained about the same throughout a component. There was some indication that choice increased less with sequences of same alternative reinforcers when a distribution of reinforcer ratios was arranged with no reversals (*e.g.*, Conditions 8, 9, and 11 in Figure 8). It seems that both these factors, the range of reinforcer ratios and reversals in the reinforcer ratios, were important in producing the increments in choice evident following sequences of same-alternative reinforcers.

Choice pulses following discontinuations were much shorter in duration, and relatively constant throughout a component (Figure 9). The levels at which choice stabilized, how-

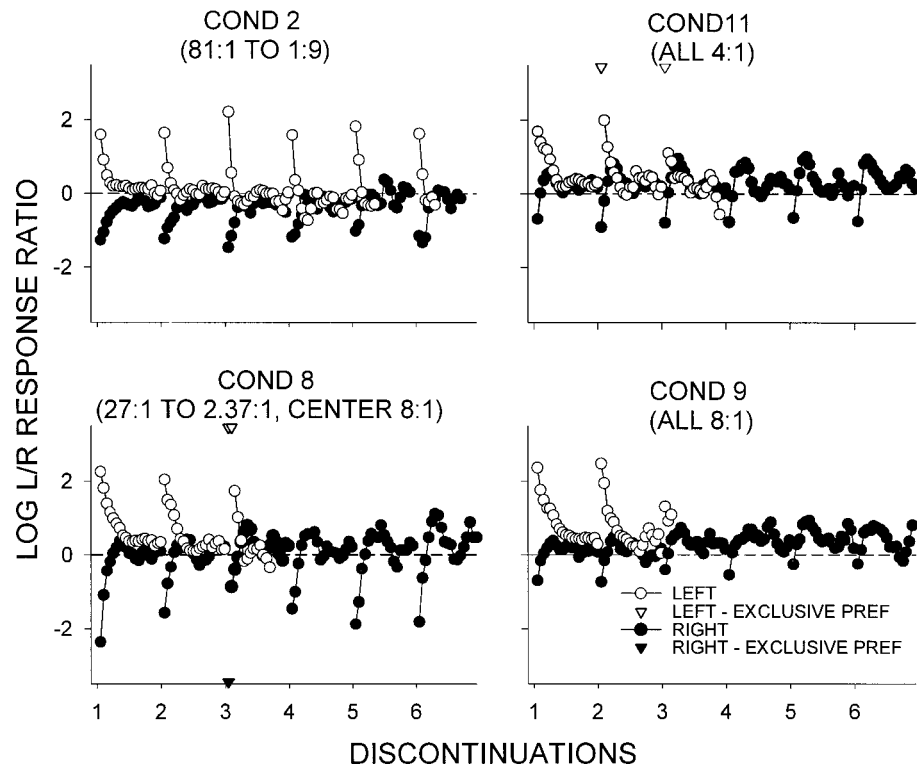


Fig. 9. The log response ratios in successive 2-s time bins in Conditions 2, 8, 9, and 11 following sequences of successive same-alternative reinforcers from the start of a component that ended with a single discontinuation. Data were omitted when a particular time bin was reached on fewer than 20 occasions. The triangles denote occasions when choice was exclusive to one alternative.

ever, depended on the sessional reinforcer ratios. These results, together with those in Figures 6 through 8, suggest that choice during long interreinforcer intervals (and perhaps periods of unsignaled extinction) might be controlled by the sessional reinforcer ratio. They did not fall to indifference as reported by Davison and Baum (2002; see also, Landon, Davison, & Elliffe, 2002). Future research could address this further by examining changes in choice during unsignaled extinction after exposure to various unequal reinforcer-ratio distributions (cf. Davison & Baum).

The behavioral effects of sequences of continuations obtained at the higher-reinforcer-rate (or larger-magnitude) alternative seen in Figures 2 through 4 are understandable in terms of the interreinforcer shifts in choice shown in Figures 6 through 8. The major differences across conditions were in the small increments in choice evident after the choice pulses had dissipated. These increments were

larger when a range of reinforcer ratios was arranged (Figure 8). Hence, when examined at a reinforcer-by-reinforcer level, successive continuations appeared to have small diminishing effects on choice in those conditions.

As outlined above, the choice pulses following discontinuations were similar across all conditions. They were brief compared to those following continuations. When compared with choice before the discontinuation, however, they were large. A discontinuation, regardless of its sequential position in a component, quickly returned choice to a level in keeping with the sessional reinforcer-rate or magnitude ratio. The changes across conditions were evident in the analyses of choice in interreinforcer intervals (Figure 9), and even clearer in the reinforcer-by-reinforcer analyses (Figures 2 through 4).

Landon and Davison (2001) showed that when discontinuations occurred often enough, the effects of sequences of continuations following a discontinuation were very

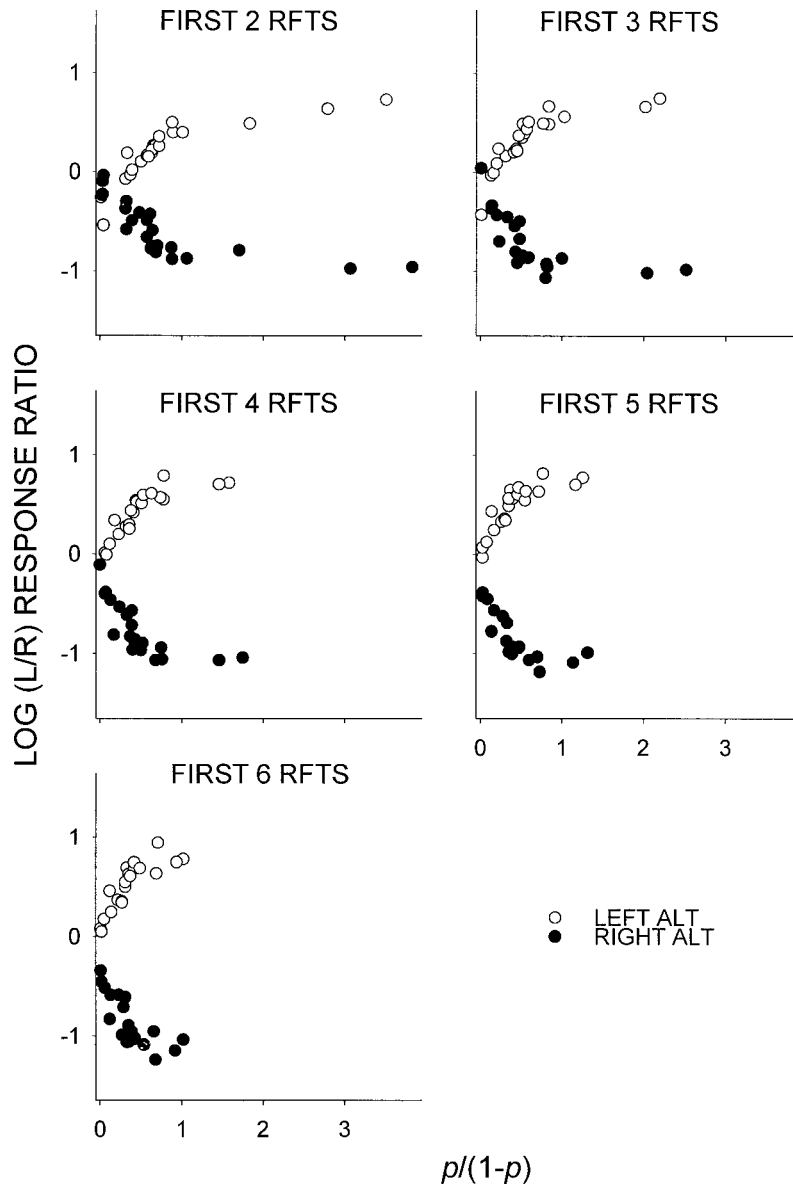


Fig. 10. Log response ratios in interreinforcer intervals following sequences of successive same-alternative reinforcers of various lengths from the beginning of a component plotted as a function of the logistic transform of the proportion of all sequences that length. The data were obtained from the present experiment and those reported previously by Landon and Davison (2001).

similar to those of a sequence of continuations obtained at the start of a component. Thus it seems that discontinuations reset choice to levels controlled by longer-term aggregations of reinforcers. Thereafter, individual reinforcers and sequences of reinforcers have strong local effects. It is possible, therefore, that in a model designed to explain

these results, a discontinuation would result in some updating of longer-term aggregations of reinforcers and deletion or resetting of shorter-term aggregations (see also Killeen & Smith, 1984).

Sequences of successive same-alternative reinforcers, broken by discontinuations, may have been important in producing the pre-



sent results. These sequences moved choice towards the alternative from which they were obtained, and their effects were apparently erased, at least in the short term, by a single discontinuation that returned choice to a level that was influenced by the sessional reinforcer ratio. Figure 5 confirmed that when the frequency of the sequences was similar (i.e., Conditions 7 and 10 and Conditions 8 and 9), the resulting behavior was similar (Figures 3 and 4 and Figures 6 and 11). Across conditions, choice following these sequences changed with the overall distribution of reinforcer ratios (see also Landon & Davison, 2001). In addition to these distributions changing, however, the frequency of the sequences of continuations also changed. Thus choice could also be examined in terms of how it differed as a function of how frequently various sequences of continuing reinforcers occurred.

Across all conditions of the present experiment and the conditions reported previously by Landon and Davison (2001), excluding Conditions 3 through 6 of the present study in which either the blackouts between the components or the reinforcer magnitudes were varied, sequences of between two and six reinforcers in length from the beginning of components were collated. Thus data from a variety of equal (Landon & Davison) and unequal reinforcer-ratio distributions were included. The proportions of these sequences that were solely successive left- or right-alternative continuing reinforcers ( $p$ ) were then calculated. The log response ratios emitted in the interreinforcer intervals following sequences of continuations for each condition were then plotted as a function of the ratio  $p/(1 - p)$ , and are shown in Figure 10. As Figure 10 shows, the relation was negatively accelerated in both directions, and more extreme choice occurred following the same sequence of confirming reinforcers when that sequence of reinforcers occurred more frequently, irrespective of the distribution of reinforcer ratios.

To summarize, the present experiment extended recent findings (Davison & Baum, 2000, 2002; Landon & Davison, 2001) to situations in which unequal reinforcer distributions were arranged. The results suggest that variables controlling choice operate at a number of levels. At one level, individual re-

inforcers affect subsequent behavior. At another, successive continuing reinforcers have cumulative effects on choice. At yet another level, when sequences of continuations occur with greater frequency, these cumulative effects are magnified. Finally, discontinuations have large effects, both at the level of the interreinforcer interval and at a more local level between reinforcers, and at a longer-term level return choice quickly to levels that change with the sessional reinforcer ratio.

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