

*EVERY REINFORCER COUNTS: REINFORCER MAGNITUDE AND  
LOCAL PREFERENCE*

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Six pigeons were trained on concurrent variable-interval schedules. Sessions consisted of seven components, each lasting 10 reinforcers, with the conditions of reinforcement differing between components. The component sequence was randomly selected without replacement. In Experiment 1, the concurrent-schedule reinforcer ratios in components were all equal to 1.0, but across components reinforcer-magnitude ratios varied from 1:7 through 7:1. Three different overall reinforcer rates were arranged across conditions. In Experiment 2, the reinforcer-rate ratios varied across components from 27:1 to 1:27, and the reinforcer-magnitude ratios for each alternative were changed across conditions from 1:7 to 7:1. The results of Experiment 1 replicated the results for changing reinforcer-rate ratios across components reported by Davison and Baum (2000, 2002): Sensitivity to reinforcer-magnitude ratios increased with increasing numbers of reinforcers in components. Sensitivity to magnitude ratio, however, fell short of sensitivity to reinforcer-rate ratio. The degree of carryover from component to component depended on the reinforcer rate. Larger reinforcers produced larger and longer postreinforcer preference pulses than did smaller reinforcers. Similar results were found in Experiment 2, except that sensitivity to reinforcer magnitude was considerably higher and was greater for magnitudes that differed more from one another. Visit durations following reinforcers measured either as number of responses emitted or time spent responding before a changeover were longer following larger than following smaller reinforcers, and were longer following sequences of same reinforcers than following other sequences. The results add to the growing body of research that informs model building at local levels.

*Key words:* choice, generalized matching, local analyses, preference pulses, pecking, pigeons

Choice in concurrent schedules—principally concurrent variable-interval (VI) schedules—as a function of reinforcer ratio is accurately described by the generalized matching relation (Baum, 1974):

$$\log \frac{B_1}{B_2} = a \log \frac{R_1}{R_2} + \log c, \quad (1)$$

where  $B$  refers to numbers of responses emitted and  $R$  to numbers of reinforcers obtained on the alternatives subscripted 1 and 2. The parameter  $a$  is called sensitivity to reinforcement and measures the rate of change in log response ratio to change in log reinforcer ratio. The parameter  $\log c$  is called inherent bias, and measures any constant proportional preference for one alternative over the other

that remained constant as reinforcer ratio was varied.

Other independent variables, such as reinforcer magnitude, reinforcer delay, reinforcer quality, and response difficulty also affect preference, and the generalized matching relation can be extended to account for the effects of these variables. Our present focus is on reinforcer magnitude, and the concatenated generalized matching relation for reinforcer rate and magnitude is:

$$\log \frac{B_1}{B_2} = a_r \log \frac{R_1}{R_2} + a_m \log \frac{M_1}{M_2} + \log c. \quad (2)$$

In Equation 2,  $M$  refers to reinforcer magnitude, and the two sensitivity parameters for the two independent variables have been discriminated by subscripts because sensitivity to magnitude is usually smaller than that to reinforcer rate (see Davison & McCarthy, 1988, for a review of this area).

Although the generalized matching relation has most often been applied to steady-state choice, it has recently been reported to occur within sessions. Davison and Baum (2000), using a procedure adapted from Belke and Heyman (1994), arranged seven un-signalized components within sessions. Each

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component lasted a fixed number of reinforcers. The reinforcer ratios in components differed and ranged in equal logarithmic steps from 1:27 to 27:1. Components were separated by a 10-s blackout. Davison and Baum found that sensitivities to reinforcer ratio of between 0.5 and 0.6 developed within components after the delivery of just six to eight reinforcers. They also found higher sensitivity values when arranged overall reinforcer rates were six per minute as compared with 2.22 per minute. When they varied the number of reinforcers per component, they found that the rate of component change had no effect on sensitivity. Landon and Davison (2001), however, found that decreasing the range of reinforcer-ratio variation across components decreased sensitivity. Finally, Davison and Baum (2002) documented two further effects: First, the effect of reinforcers obtained on one component on choice in the next component decreased with increasing blackout duration between components, and this decrease was faster than the decrease that occurred if components were demarcated by unsignaled periods of extinction. Second, they showed that reinforcer delivery within components was followed by a "pulse" in preference to the just-reinforced alternative that was followed by a decrement in choice toward indifference (zero preference).

Preference pulses following reinforcers have also been found in analyses of steady-state concurrent schedule performance. Landon, Davison, and Elliffe (2003) varied reinforcer magnitudes over five conditions with the same reinforcer rates arranged on both alternatives. Preference pulses (their Figure 5) were greater, and lasted longer, following larger reinforcers. Mean response-allocation sensitivity to reinforcer magnitude ( $a_m$  in Equation 2) was 0.76 (range 0.70 to 0.87). Although these values were generally higher than those previously found for reinforcer magnitude, they were consistently smaller than sensitivities to reinforcer rate obtained from the same subjects (Landon, Davison, & Elliffe, 2002). This difference between sensitivity to reinforcer rate and magnitude has been commonly reported (Davison & McCarthy, 1988).

The questions we ask in the present experiment, using the Davison and Baum (2000) procedure, are these: First, is choice across

reinforcers within components affected by reinforcer magnitude? Given that animals prefer larger-magnitude reinforcers, we would expect this might be the case. Second, are the sizes and the durations of pulses in preference following reinforcers affected by reinforcer magnitude as found by Landon et al. (2003)? Third, can we see any interactions between reinforcer rate and reinforcer magnitude within sessions? Davison (1988), in a steady-state experiment, showed that choice between different reinforcer magnitudes decreased at higher overall reinforcer rates, and the same result was reported by Logue and Chavarro (1987). In Experiment 1, we varied reinforcer-magnitude ratios between components within sessions, keeping reinforcer-rate ratios constant and equal between components, and we varied the overall reinforcer rate across conditions. In Experiment 2, we kept the reinforcer-magnitude ratio constant and varied the reinforcer-rate ratios across components in the same way as did Davison and Baum, keeping the overall reinforcer rate at 2.22 per minute. Across conditions, we varied reinforcer-magnitude ratios.

The procedure used to vary reinforcer magnitude was the same as that used by Landon et al. (2003). In four pilot conditions, not reported here, we varied the duration of reinforcers in order to vary magnitude. This procedure is known to have problems, such as food magazines being emptied out during a long presentation and possibly not refilling completely before the next presentation (Landon et al., 2003; Epstein, 1985). The initial conditions that we conducted provided data that were similar to those reported here, but choice varied considerably across subjects. We suspected that different subjects were eating different amounts during the same duration. To promote more uniformity, we changed to the procedure of varying magnitude by presenting the hopper for 1.2 s at a time and varying the number of presentations, with 0.5 s between presentations.

## EXPERIMENT 1

### METHOD

#### *Subjects*

Six homing pigeons, numbered 21 to 26, served. Water and grit were available at all

Table 1

Sequence of experimental conditions, baseline schedules, and reinforcer-magnitude conditions in Experiment 1. Component reinforcer-rate ratios were all 1:1.

Condi- tion	VI schedule (s)	Number of 1.2-s reinforcers	
		Left	Right
1	27	1,2,3,4,5,6,7	7,6,5,4,3,2,1
2	10	1,2,3,4,5,6,7	1,2,3,4,5,6,7
3	40	1,2,3,4,5,6,7	1,2,3,4,5,6,7

times. These pigeons had previously been trained on concurrent VI schedules, and immediately prior to this experiment had been exposed to procedures similar to those used here, except that reinforcer magnitudes had been arranged as reinforcer durations. Because body weight tended to rise above the usual 85% level for some pigeons with the reinforcer-magnitude procedure used here, Pigeons 22, 23, and 25 were maintained at 110%, 110%, and 100%, respectively, of their free-feeding body weights (which had been determined about 2 years before the first condition reported here). All 3 of these pigeons worked well and emitted high response rates.

#### Apparatus

The pigeons were housed individually in cages (375 mm high by 370 mm deep by 370 mm wide) that also served as the experimental chambers. On one wall of the cage were three plastic pecking keys (20 mm diameter) set 100 mm apart center to center and 220 mm from a wooden perch situated 100 mm from the wall and 20 mm from the floor. Only the left and right keys were used, and each could be illuminated yellow, green, or red with light-emitting diodes situated behind the translucent plastic keys. Responses to illuminated keys exceeding about 0.1 N were counted. A magazine aperture (40 mm by 40 mm) was located beneath the center key, 60 mm from the perch. During a reinforcer, the keylights were extinguished, the aperture was illuminated, and the hopper, containing wheat, was raised for 1.2 s a number of times depending on the response emitted and the condition (Table 1). The hopper was lowered for 0.5 s between presentations. The subjects could see and hear pigeons in other experiments, but no personnel entered the room while the experiments were in progress. At

right-angles to the perch described above, parallel to the front of the cage, was a container that allowed the pigeons to gain access to water and grit at any time.

#### Procedure

The pigeons required no shaping or magazine training and were placed directly on the first condition of the experiment.

Sessions were conducted daily commencing at 1:00 a.m. following lighting of the room at 12:00 a.m. The room lights were extinguished at 4:00 p.m. each day. The 6 pigeons were studied in order with sessions lasting until 70 reinforcers had been delivered or until 45 min had elapsed, whichever occurred first. A reinforcer in the current experiment was defined as a sequence of between one and seven 1.2-s hopper presentations. Sessions commenced with the left and right keylights illuminated yellow, which signaled the availability of a VI schedule on each key. Sessions were divided into seven components within sessions with the sequence of components selected randomly without replacement. No signals differentiated among components. All components lasted for 10 reinforcers, and the components were separated by the blackout of both keys for 10 s. Sessions ended with the extinguishing of both keylights.

A changeover delay (COD; Herrnstein, 1961) was in effect throughout. Following a changeover to either key, a reinforcer could not be obtained for responding at the key switched to until 2 s had elapsed from the changeover (i.e., the first response at the key).

A computer in an adjacent room controlled and recorded all experimental events using MED-PC® software. Each condition (see Table 1) lasted for 50 sessions, and the data used in the analysis were from the last 35 sessions of the condition. Davison and Baum (2000) showed that such data were stable.

In Experiment 1, we arranged three conditions (1 to 3) in which the reinforcer-magnitude ratios (that is, the ratios of the numbers of 1.2-s hopper presentations) were 1:7, 2:6, 3:5, 4:4, 5:3, 6:2, and 7:1, and the overall reinforcer rate was varied over conditions from 2.22 to 6 to 1.5 reinforcers per minute, in that order.

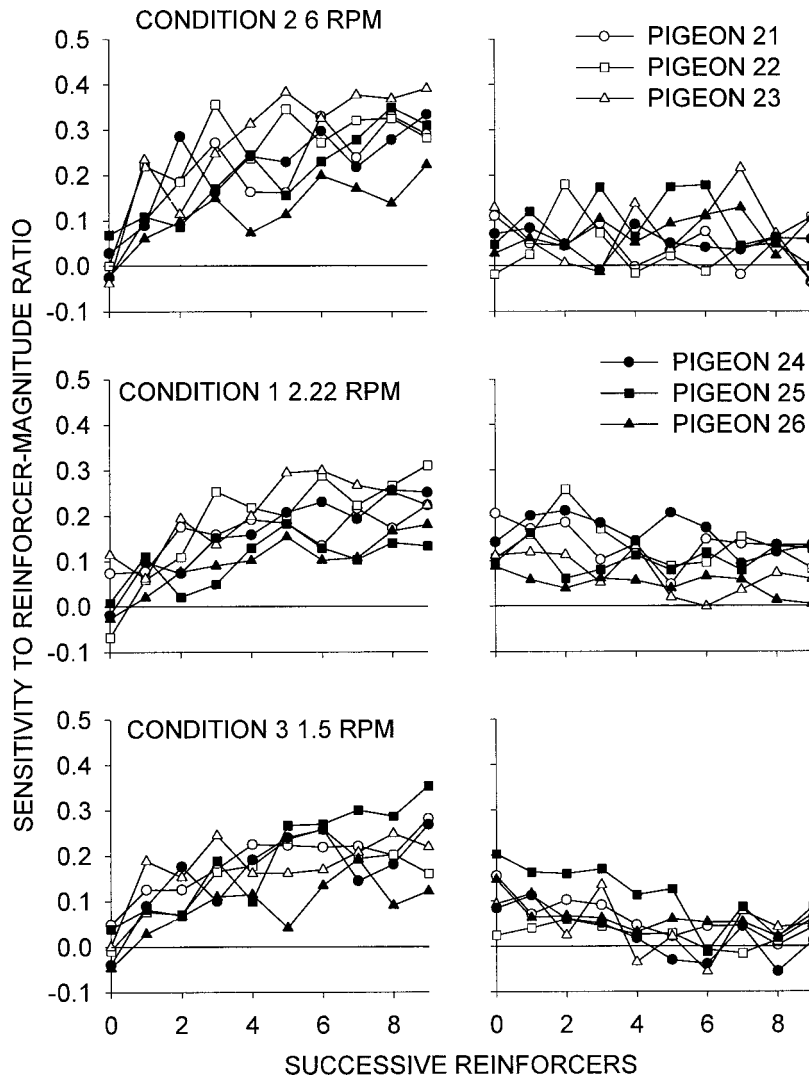


Fig. 1. Experiment 1. Sensitivity to reinforcer-magnitude ratio obtained using Equation 2 following successive reinforcers in components. The left panel shows sensitivity in the current component, and the right panel shows sensitivity to the previous-component magnitude ratio. The data for all subjects are shown.

### RESULTS

Figure 1 shows sensitivities to reinforcer-magnitude ratio (the ratio of the number of 1.2-s reinforcers) in both the current and prior component for the individual pigeons for Conditions 1 to 3 in which the overall arranged reinforcer rates were 2.22, 6, and 1.5 reinforcers per minute. The sensitivities were obtained using multiple-linear regressions of log response ratio versus log reinforcer-magnitude ratio (as in Davison & Baum, 2000). The left column of graphs shows sensitivity to the reinforcer-magnitude ratio in the current

component. The right column shows sensitivity to magnitude ratio in the prior component (i.e., carryover). In all three conditions, for all subjects, sensitivity to magnitude ratio in the current component increased from levels close to zero before the first reinforcer was delivered (mean sensitivity across subjects 0.01, 0.00, and 0.00 for the three conditions) to mean values of 0.22, 0.31, and 0.23 after 9 reinforcers had been delivered. Individuals showed similar sensitivity changes. Nonparametric trend tests showed no significant changes in sensitivity values to the current

component with changes in overall reinforcer rate. Sensitivity to magnitude ratio in the prior component (*carryover sensitivity*) depended on overall reinforcer rate. Falling sensitivities (as found with varying reinforcer-rate ratio across components; Davison & Baum, 2000, 2002) were most evident at the lowest overall reinforcer rate (1.5 reinforcers per minute, Condition 3). In this condition, the mean carryover sensitivity at the start of a component was 0.12, and at the end it was 0.05. But, at the highest reinforcer rate we studied (six reinforcers per minute arranged, Condition 2), the falling pattern was absent, and carryover appeared to be relatively constant and positive throughout the next component (mean values of 0.06 at the start of the component and 0.03 at the end of the component). Condition 1 (2.22 reinforcers per minute) showed an intermediate pattern, with sensitivity values of 0.12 and 0.09 at the start and at the end. On the basis of the similarity of results across pigeons, the remainder of the analyses will generally use grouped data rather than individual data.

Figures 2, 3, and 4 show group log response ratios for each response following reinforcers on the left and right alternatives in each component for Conditions 2, 1, and 3 (ordered according to decreasing overall reinforcer rate). Similar analyses for individuals are shown in Appendix A, Figures A1 to A6. Response ratios were calculated by summing the number of responses in each ordinal position (e.g., the first, the second, etc.) following a reinforcer across the 35 presentations of a component and across all the reinforcers of each magnitude within the component. The general pattern was clear across all three conditions: Preference following reinforcers was towards, often strongly towards, the alternative from which the last reinforcer had been obtained. We refer to this transitory preference as a pulse because thereafter preferences moved toward indifference. The functions for the two reinforcers converged and crossed two or three times within the 40 responses analyzed. One may guess that these oscillations resulted from changing over between alternatives. Also evident from these graphs is that larger reinforcers generally produced larger and longer preference pulses. Small reinforcers (e.g., the single 1.2-s reinforcers in Components 1 and 7) usually

produced small and transient preference pulses that were shortly followed by a period of preference for the larger reinforcer-magnitude alternative. These patterns were obscured to some extent because of an overall bias in favor of the left key.

Apart from Pigeon 25, similar patterns of preference change after reinforcers were shown by all individuals (Figures A1 to A6). Pigeon 25 showed a strong overall bias toward the left key, with strong preference toward the left key even following right-key reinforcers; but as for the other pigeons, this preference was not as great as left-key preference following left-key reinforcers. Pigeon 25 also failed to show clear oscillations in preference between alternatives following reinforcers.

Some of the features discussed above are summarized in Figure 5. In the top panel, to show the size of preference pulses after reinforcers, the log response ratio averaged across pigeons is shown as a function of the log reinforcer-magnitude ratio. Initial pulse size increased as reinforcer magnitude increased from one to three or four 1.2-s deliveries, and then remained relatively constant. Overall reinforcer rate had no consistent effect on the initial size of preference pulses. Responding after reinforcers was generally biased toward the left key. The lower panel shows the number of responses that had been emitted since a reinforcer at the point at which the log response ratio changed sign (the response number just beyond the point of indifference). On this figure, the maximum was 40 (the number of responses after reinforcer analyzed); response numbers at 40 indicate that 40 or more responses were emitted. The pattern was similar to the top panel: As reinforcer magnitudes increased, on the average more responses occurred on the just-reinforced alternative before changing to the other alternative.

#### DISCUSSION

Experiment 1 replicated the procedure used by Davison and Baum (2000), but replaced their variation of reinforcer-rate ratios across components with a variation of reinforcer-magnitude ratios. The results generally showed that reinforcer magnitudes affect the behavior in a similar fashion to reinforcer rates, but some differences were evident.

Figure 1 showed that sensitivity to rein-

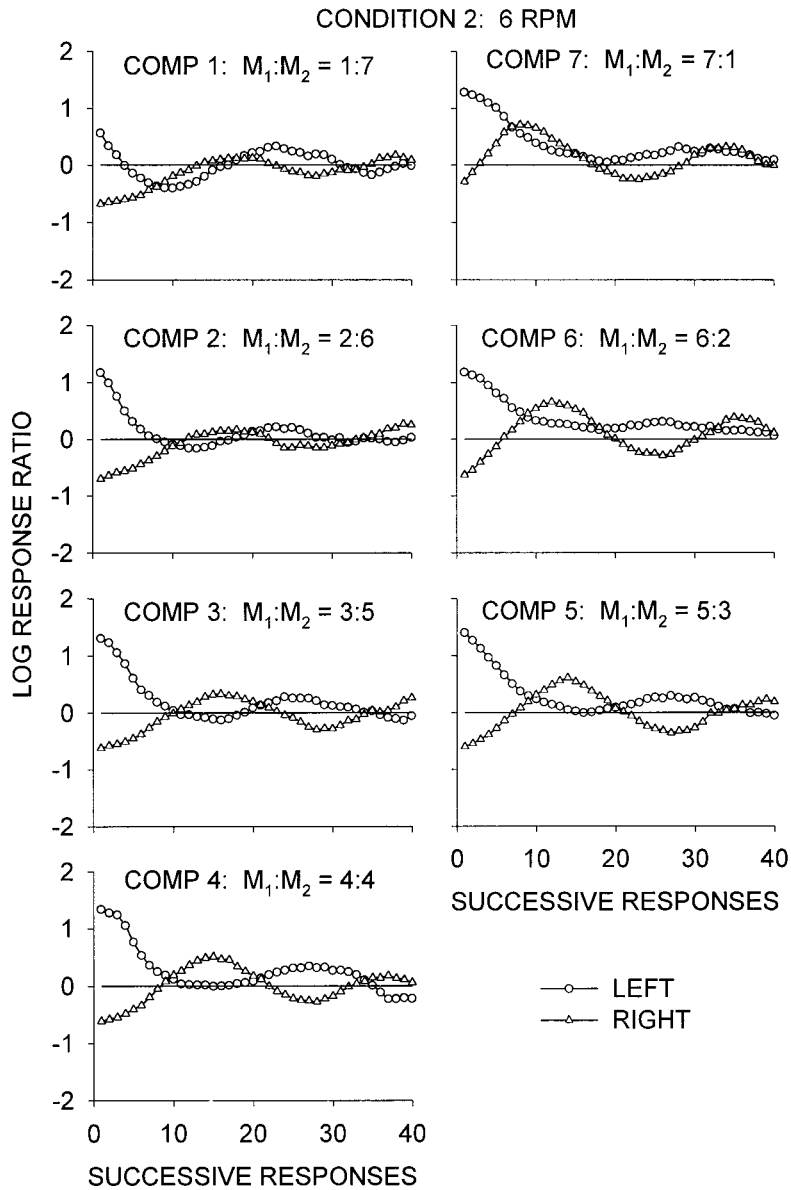


Fig. 2. Experiment 1. Condition 2 (six reinforcers per minute). Log left/right response ratios at each response up to 40 responses after left- and right-key reinforcers. The data are shown separately for all seven reinforcer-magnitude ratios. The data were averaged across the 6 pigeons.

forcement increased across successive reinforcers in components in similar fashion to the results of Davison and Baum (2000), and that individual subjects showed similar patterns. Comparing sensitivity changes with successive reinforcers between reinforcer-magnitude variation and reinforcer-rate variation (Davison & Baum), sensitivities generally remained lower with reinforcer-magnitude var-

iation. This would be expected from previous steady-state research that generally found sensitivity to magnitude was less than sensitivity to rate (Davison & McCarthy, 1988; Schneider, 1973; Todorov, 1973). Those previous findings were, thus, supported in this different procedure and at this local level of analysis. Sensitivity to reinforcer-magnitude values found here were also consistently lower than

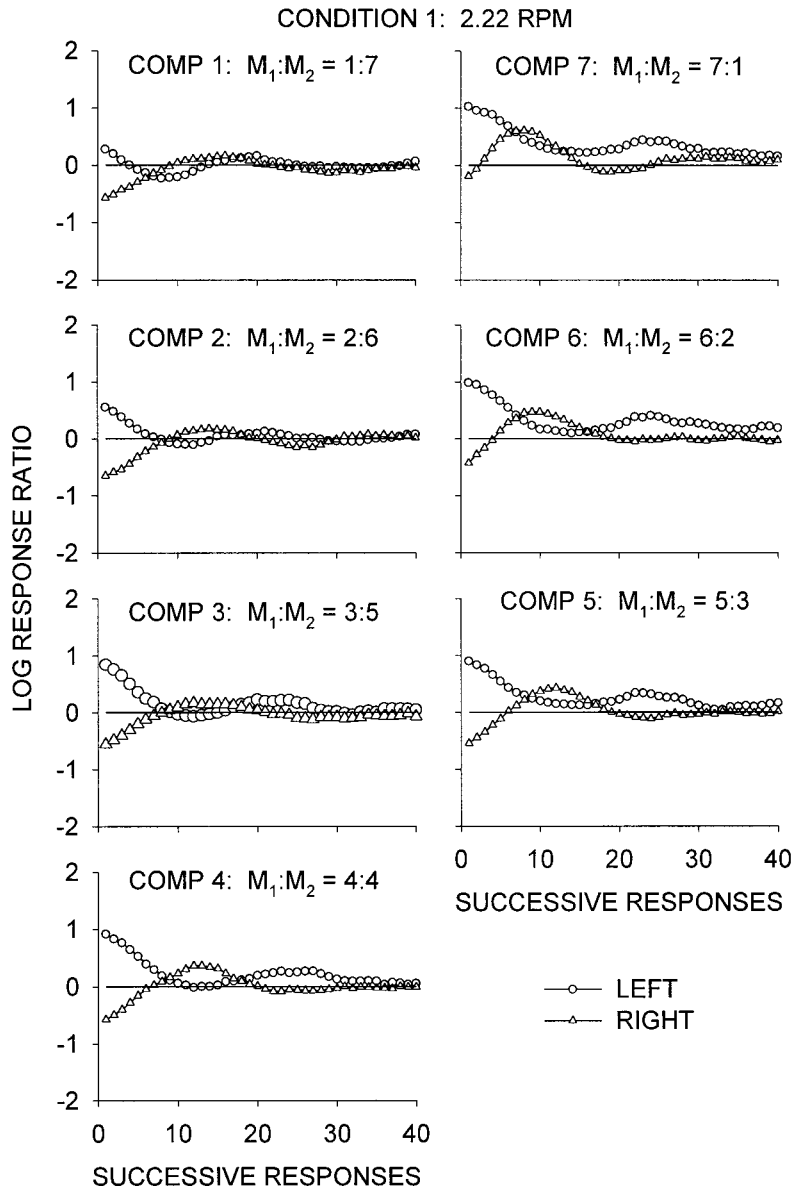


Fig. 3. Experiment 1. Condition 1 (2.22 reinforcers per minute). Log response ratios at each response up to 40 responses after left- and right-key reinforcers. The data are shown separately for all seven reinforcer-magnitude ratios. The data were averaged across the 6 pigeons.

those reported by Landon et al. (2003) using a steady-state procedure. This may arise simply because sensitivity values do not reach asymptotic values after just 10 reinforcers. Davison and Baum also found that sensitivity to reinforcer rate after 10 reinforcers was less than the usual steady-state value.

Overall reinforcer rate appeared to have no effect on sensitivity to reinforcer-magni-

tude ratio (Figure 1). Although this might appear contrary to the finding by Davison & Baum (2000) that increasing overall reinforcer rate increased sensitivity to reinforcer-rate ratios, the parallel effect with reinforcer magnitude might be variation of overall reinforcer magnitude (e.g., Logue & Chavarro, 1987). Davison (1988) reported that increasing overall reinforcer rate decreased sensitiv-

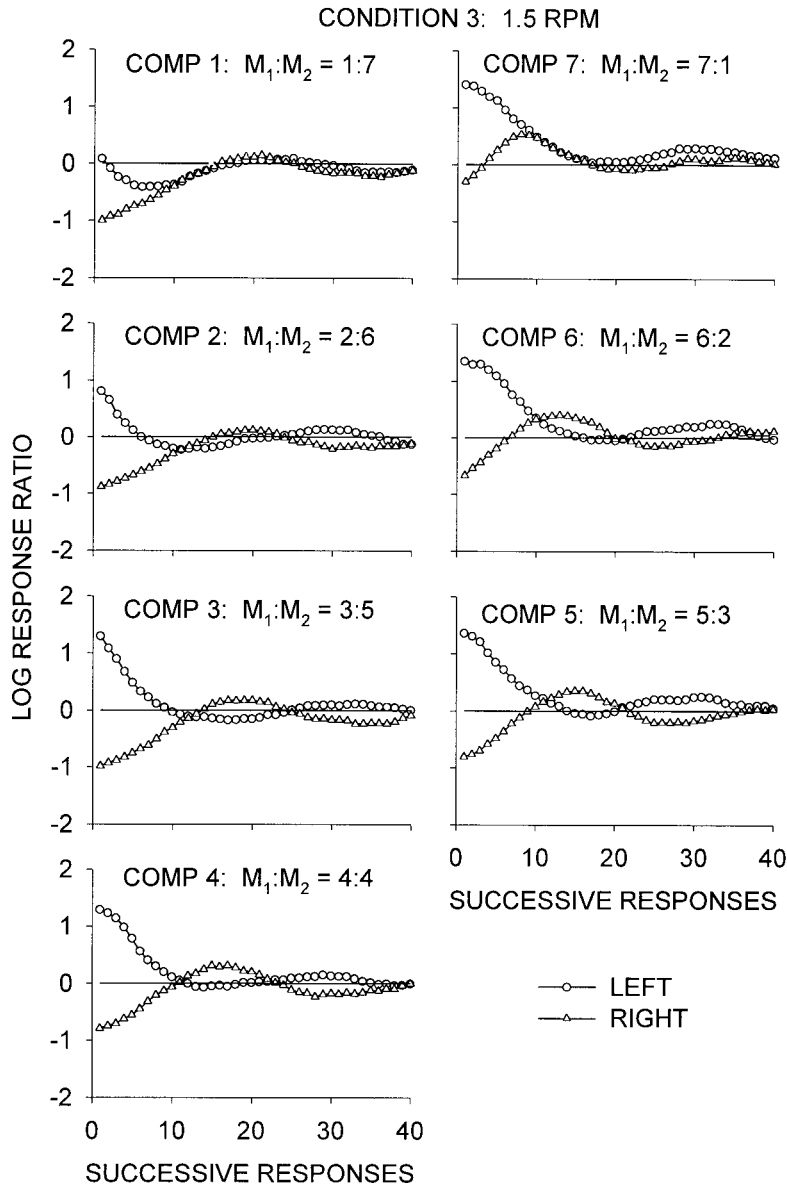


Fig. 4. Experiment 1. Condition 3 (1.5 reinforcers per minute). Log response ratios at each response up to 40 responses after left- and right-key reinforcers. The data are shown separately for all seven reinforcer-magnitude ratios. The data were averaged across the 6 pigeons.

ity to reinforcer duration in a steady-state procedure. Our failure to find a similar effect here could result from our using number of discrete reinforcers rather than reinforcer duration.

One might be surprised that sensitivity rose no faster for reinforcer magnitude than for rate, apart from the asymptotic sensitivities. In each component, if number of 1.2-s rein-

forcers were discriminated, the first complete reinforcer delivered should be sufficient to signal unequivocally the magnitude conditions in that component. We might expect, therefore, that performance would be under precise stimulus control, at least in components that arranged different numbers of 1.2-s hopper presentations on the two alternatives. We would expect this control to be



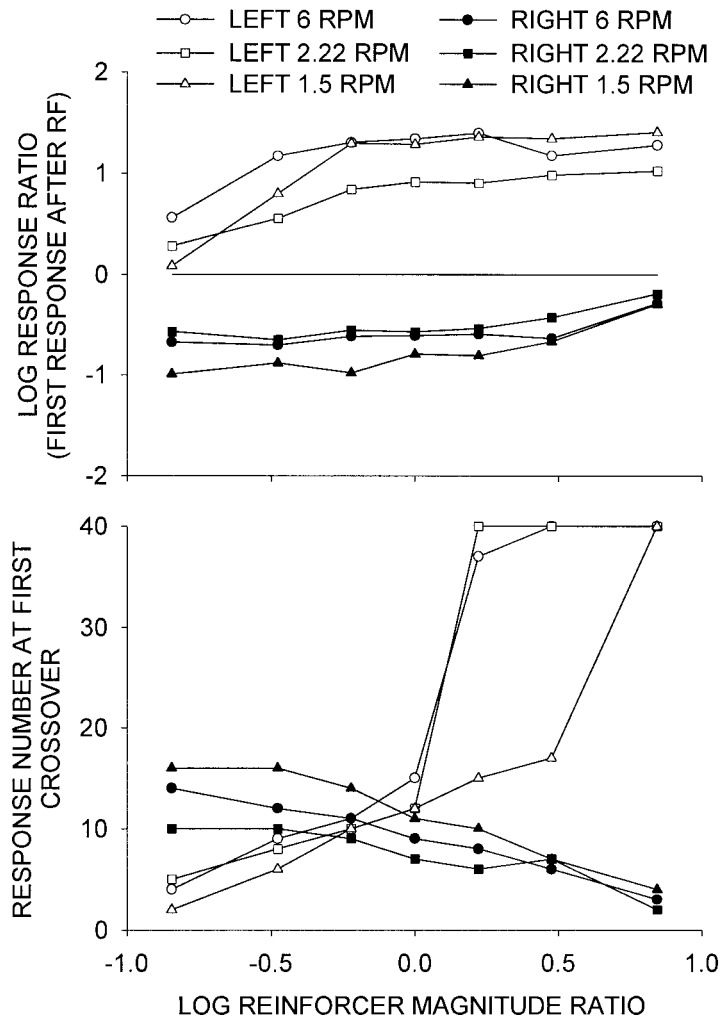


Fig. 5. Experiment 1. Upper panel: Log response ratios at the first response after left- and right-key reinforcers in Conditions 1, 2, and 3. Lower panel: The number of responses after reinforcers on the left and right keys at which postreinforcer preference pulses crossed indifference. The data in both panels were averaged across the 6 pigeons.

similar to that found by Krägeloh and Davison (2003) when they differentially signaled each component with different frequencies of flashing light. They found substantial sensitivity values *before* the first reinforcer, whereas here we would expect to find this control *following* the first reinforcer. There was no evidence, however, of such an effect. Thus, either the pigeons were unable to discriminate differences in reinforcer numbers or the contingencies failed to support such a discrimination. The former seems unlikely because the different-sized reinforcers had different following-reinforcer effects. Some research has shown, however, that a current reinforcer

may eliminate the effect of previous reinforcers (Killeen & Smith, 1984). Although we offer no explanation here, one might be found by studying the discriminability of reinforcer durations.

Another difference between reinforcer-magnitude ratio and reinforcer-rate ratio was in the time course of carryover of the previous component's ratio into the present component. With magnitude variation, overall reinforcer rate mattered: When it was high, little decrease in carryover sensitivity occurred in the next component, but when it was low, carryover decreased (Figure 1). With reinforcer-rate ratio, carryover always de-

creased (Davison & Baum, 2000). This difference suggests an interaction between reinforcer rate and magnitude that is driven by previous-component reinforcer-magnitude ratio, and not by current-component ratio.

Our analysis of preference at each of the first 40 responses after a reinforcer (Figures 2, 3, and 4) showed that both more extreme and longer preference pulses followed larger reinforcers, although up to a limit (Figure 5). Similar preference pulses following reinforcers were reported by Landon et al. (2002, 2003) in a steady-state procedure, and the changes found here are consonant with their findings. Landon et al. (2003) suggested that a substantial part of molar, steady-state, sensitivity to reinforcement was due to variation, from one reinforcer ratio to another, in the relative frequency of postreinforcer preference pulses. Thus, in the steady state, when reinforcer magnitudes are varied (and rates are kept constant), the usual lower sensitivity to magnitude than to rate might result from constancy of different-sized preference pulses following different reinforcer magnitudes; whereas the higher sensitivity when reinforcer rates are varied might result from changes in relative frequency of different-sized preference pulses with changing frequencies of same-sized reinforcers. Sensitivity to reinforcer magnitude results from different-sized preference pulses, whereas sensitivity to reinforcer rate results from both different relative sized and frequencies of preference pulses.

## EXPERIMENT 2

Within each condition of Experiment 2, we maintained a constant reinforcer-magnitude ratio across the seven components and varied the reinforcer-rate ratio between components in exactly the same way as Davison and Baum (2000). Between conditions, we varied the reinforcer-magnitude ratio from 1:7 through 7:1. This experiment was designed to provide more information on three aspects of performance. First, it provided further information on the sizes of preference pulses after smaller and larger reinforcers. Second, it allowed comparison of sensitivity to reinforcer-rate ratio with sensitivity to reinforcer-magnitude ratio obtained in Experiment 1; and third, it better allowed us to see interactions between

Table 2

Sequence of experimental conditions, baseline schedules, and reinforcer-magnitude conditions in Experiment 2. Component reinforcer-rate ratios were 1:27, 1:9, 1:3, 1:1, 3:1, 9:1, and 27:1.

Condition	VI schedule (s)	Number of 1.2-s reinforcers	
		Left	Right
4	40	4	4
5	40	7	1
6	40	2	6
7	40	5	3
8	40	3	5
9	40	6	2
10	40	1	7

reinforcer magnitude and reinforcer rate in between reinforcers.

## METHOD

### *Subjects and Apparatus*

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

### *Procedure*

The experimental procedure and data collection were the same as in Experiment 1. Experiment 2 arranged an overall reinforcer rate of 1.5 per minute in all conditions. In each condition, the components (randomly ordered without replacement) arranged reinforcer-rate ratios of 1:27, 1:9, 1:3, 1:1, 3:1, 9:1, and 27:1. Each condition arranged a constant reinforcer-magnitude ratio (Table 2) which had been used within conditions in Experiment 1.

## RESULTS

Figure 6 shows similar graphs to those shown in Figure 1 for data grouped across pigeons. The group data shown are representative of the data from individuals (see Appendix). Each graph shows the results of a multiple linear regression using two independent variables: the reinforcer-rate ratios in the current and previous component for successive reinforcer numbers in the current component. These regressions provide two sensitivity parameters and an intercept. Given that reinforcer-magnitude ratio across components was constant in each condition, this intercept represents the response bias caused by the reinforcer-magnitude ratio. If this measure is divided by the log magnitude ratio in

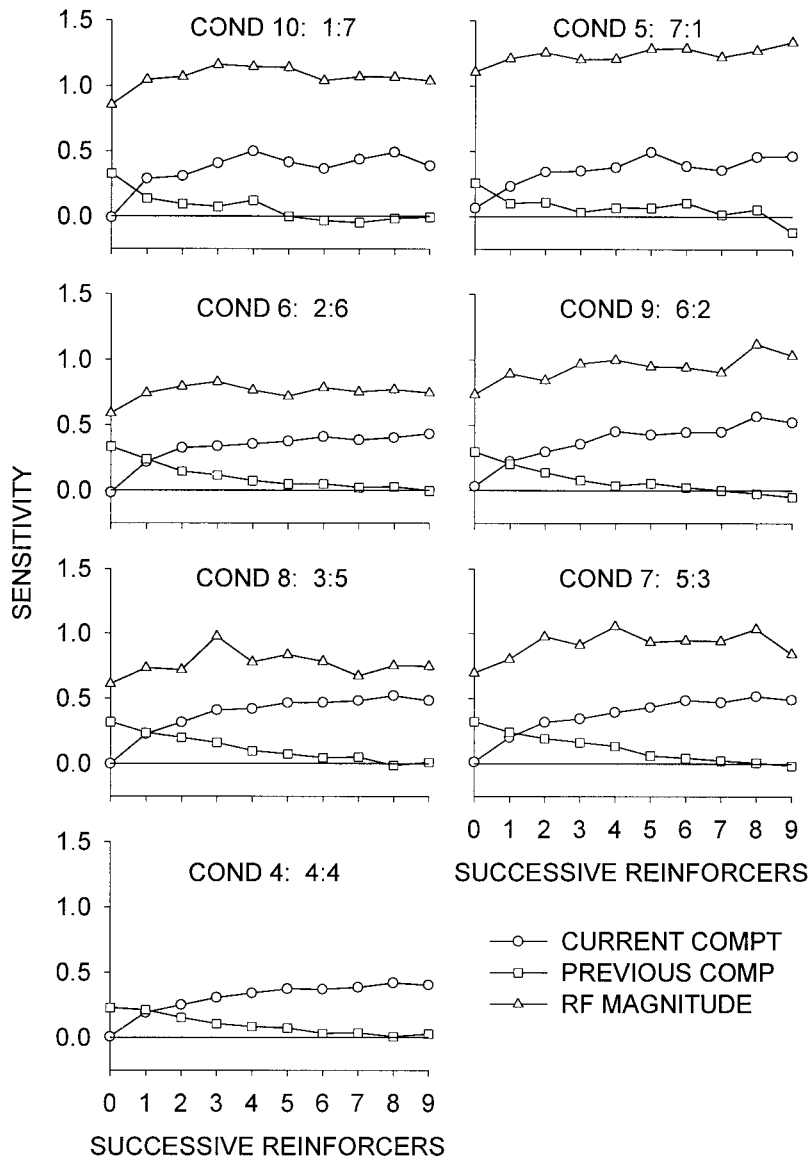


Fig. 6. Experiment 2. Sensitivity to reinforcer-rate ratios obtained using Equation 2 following successive reinforcers in components. Each panel shows sensitivity to the current-component and the prior-component reinforcer-rate ratios, and sensitivity to the reinforcer-magnitude ratio in that condition. The data were averaged across the 6 pigeons.

that condition, an estimate of sensitivity to reinforcer-magnitude ratio is obtained; however, this cannot be done for Condition 4, in which log magnitude ratio was zero. These sensitivity estimates appear in Figure 6 as triangles. In each condition, sensitivity to the current reinforcer-rate ratio increased progressively with successive reinforcers from a mean of 0.01 (range -0.02 to 0.06) before the first reinforcer to 0.45 (range 0.39 to

0.52) after the ninth reinforcer. Sensitivity to the previous reinforcer-rate ratio decreased progressively with increasing component reinforcers from a mean of 0.30 (range 0.23 to 0.33) before the first reinforcer to -0.02 (range -0.12 to 0.03) after the ninth reinforcer. Carryover sensitivity dropped close to zero—no effect of the previous component reinforcer-rate ratio—after five to seven reinforcers. These results were similar, both in

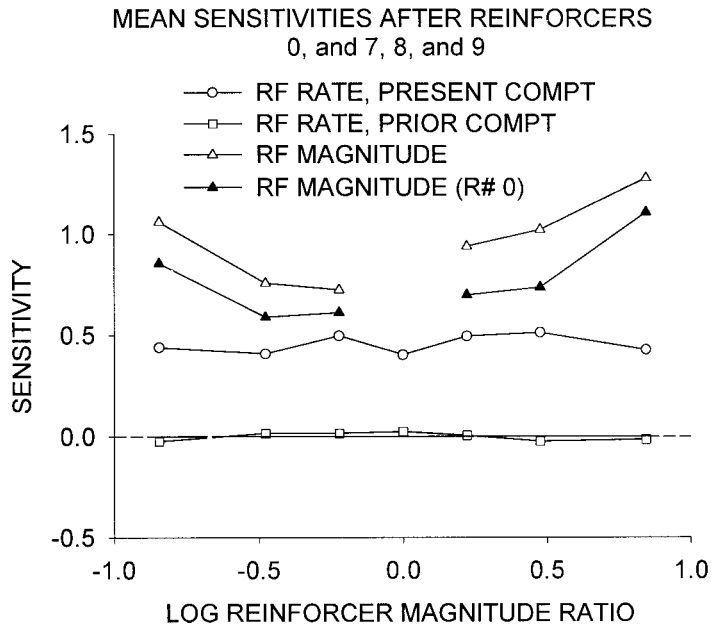


Fig. 7. Experiment 2. Sensitivity to present-component and prior-component reinforcer-rate ratios and sensitivities to reinforcer-magnitude ratios both prior to the first component reinforcer (Rf. 0) and averaged across the last three reinforcers in components (Rfs. 7, 8, and 9) as a function of log reinforcer-magnitude ratios. These data are the same as those plotted in Figure 6.

the directional changes and in the size of sensitivity values, to those previously reported (Davison & Baum, 2000, 2002) for reinforcer rate. (Condition 4, with equal reinforcer magnitudes, is the closest comparison to previous research.) Sensitivity to reinforcer magnitude increased from a mean of 0.77 (range 0.59 to 1.11) before the first reinforcer to 0.96 (range 0.75 to 1.34) after the ninth reinforcer.

Asymptotic sensitivity to reinforcer-magnitude ratios at the end of components also depended on the size of the reinforcer-magnitude ratio, and this effect is summarized in Figure 7, which shows how each of the three sensitivity measures (to previous-component and current-component reinforcer-rate ratio and to reinforcer-magnitude ratio) changed with reinforcer-magnitude ratio. The mean reinforcer-rate sensitivity to both the current and previous component averaged over Reinforcers 7 to 9 was unaffected by the reinforcer-magnitude ratio. Reinforcer-magnitude sensitivity is shown averaged over Reinforcers 7 to 9 and also, for comparison, for choice before the first reinforcer. Both sets of magnitude sensitivities show the same

pattern: Magnitude sensitivity increased as magnitude ratio became more extreme. Figure 7 highlights another result: Magnitude sensitivities were consistently lower before the first component reinforcer than after Reinforcers 7 to 9.

Figures 8 and 9 show log response ratios up to 40 responses after each reinforcer (cf. Figures 2 to 4) for Conditions 4 (4:4 magnitude ratio) and 6 (2:6 magnitude ratio). These two conditions were selected as representative of the preference pulses that occurred after reinforcers in Experiment 2, though when magnitude ratios of 1:7 and 7:1 were arranged, preference pulses after the larger reinforcer were often infinite (that is, one response count was zero). Similar analyses for individual pigeons are shown in the Appendix (Figures A7 to A10). Three effects are suggested by these figures: First, with equal reinforcer magnitudes (Figure 8 and Figures A7 and A8), preference pulses on the lower reinforcer-rate alternative were smaller and shorter in duration than those on the higher-rate alternative. Second, apart from one anomalous instance in Figure 8 ( $R_1/R_2 = 27:1$ ), in contrast with Figures 2 to 4, pref-

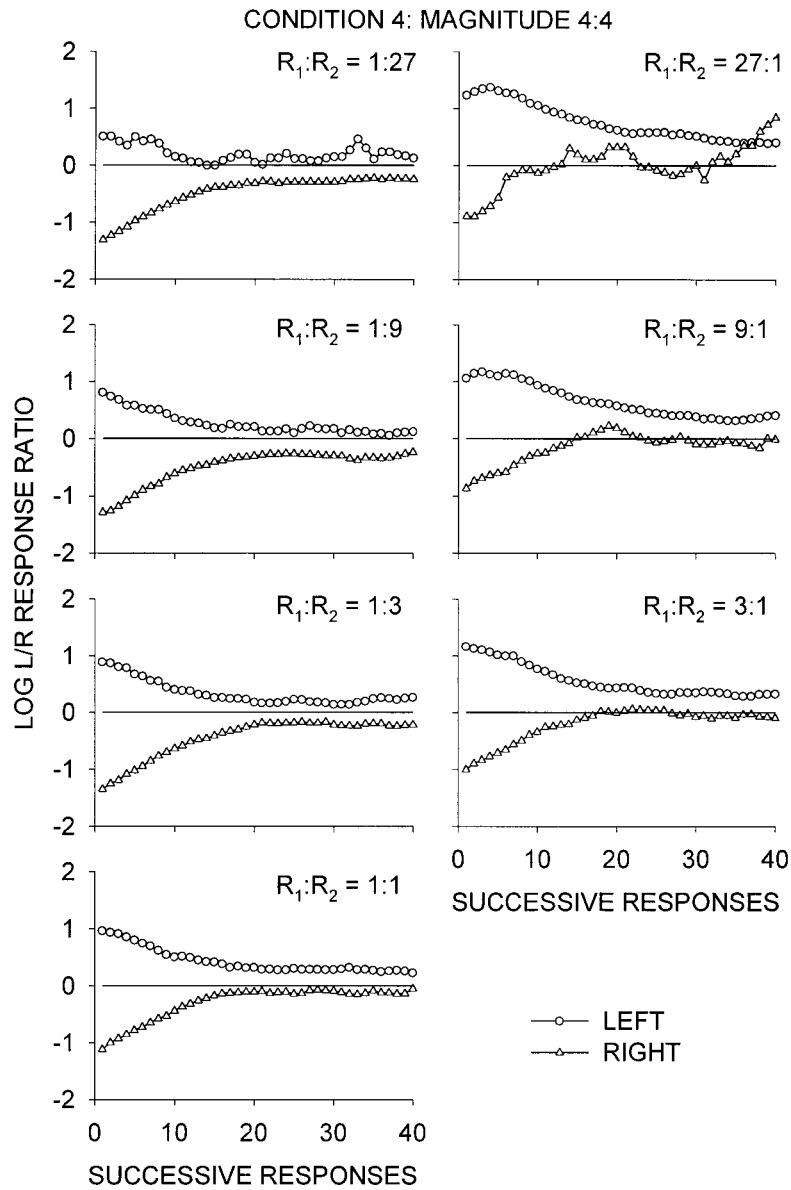


Fig. 8. Experiment 2, Condition 4 (both alternatives Magnitude-4 reinforcers). Log response ratios at each response up to 40 responses after left- and right-key reinforcers. The data are shown separately for all seven reinforcer-rate ratios. The data were averaged across the 6 pigeons.

erence differences following left and right reinforcers were maintained for more than 40 responses. Third, judged against indifference (solid lines in Figure 9), preference pulses after smaller reinforcers were smaller and shorter than those after larger reinforcers. As the reinforcer magnitudes for the left and right responses were different, however, the size of pulses might be assessed by the dis-

tance away from the mean response ratios in the components rather than from indifference. These means are shown in Figure 9 by broken lines. Judged against the mean log response ratio in each component, smaller reinforcer magnitudes still produced smaller preference pulses, but when frequency of smaller-magnitude reinforcers was low (left column of graphs in Figures 8 and 9), pref-

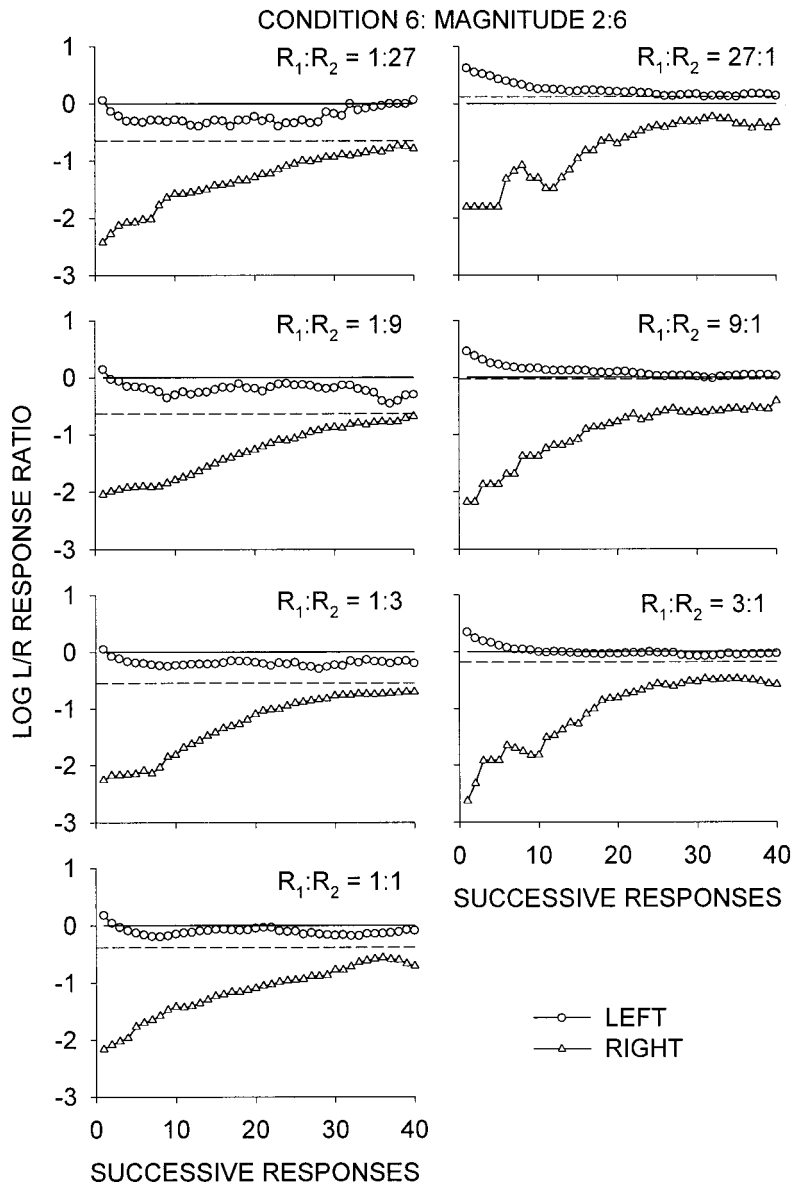


Fig. 9. Experiment 2, Condition 6 (left-key Magnitude 2, right-key Magnitude 6). Log response ratios at each response up to 40 responses after left- and right-key reinforcers. The data are shown separately for all seven reinforcer-rate ratios. The data were averaged across the 6 pigeons.

erence after the smaller magnitude dropped below zero but remained above the mean preference level, whereas preference for the larger magnitude approached the mean preference within the 40 responses. These patterns were generally true for each individual (Figures A7 to A10), though the performance of Pigeon 25 remained somewhat idiosyncratic.

Figure 10 shows a further analysis of postreinforcer pulses showing the effects on preference of continuing sequences of left and right reinforcers from the start of components. This figure shows pulses for 100 responses after sequences of one to six same-alternative reinforcers in Conditions 4 (magnitudes of 4 and 4), 12 (magnitudes of 3 and 5), and 6 (magnitudes of 2 and 6). Also

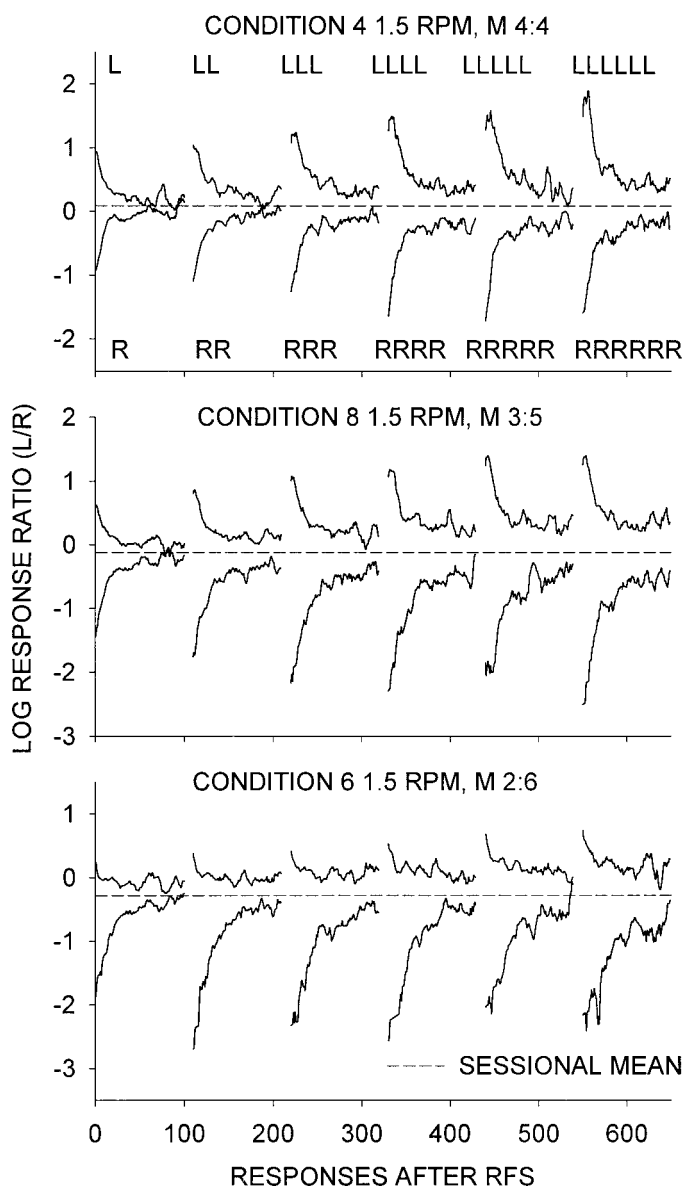


Fig. 10. Experiment 2. Preference pulses after reinforcers on the two alternatives following continued sequences of left- and right-key reinforcers. Dashed lines show sessional mean log response ratios. The upper panel shows data from Condition 4 (reinforcer magnitudes of 4 and 4), and the lower panel shows data from Condition 6 (reinforcer magnitudes of 2 and 6). The data were averaged across the 6 pigeons.

shown (dashed lines) are the means of response ratios averaged over all 35 sessions. In general, both the peaks of the pulses and the levels reached for responses 40 to 100 postreinforcer (described hereafter as baseline levels) became more extreme with increasing sequence length. The size of the pulses—the difference between the peaks and the base-

line levels—also appeared to increase. The peaks for the Magnitude-6 reinforcer sequences, however, seemed to level out at about  $-2.5$  whereas the baseline levels continued to become more extreme. Overall, although the sizes of the preference pulses were determined by the reinforcer magnitudes, the changes in both peaks and baseline

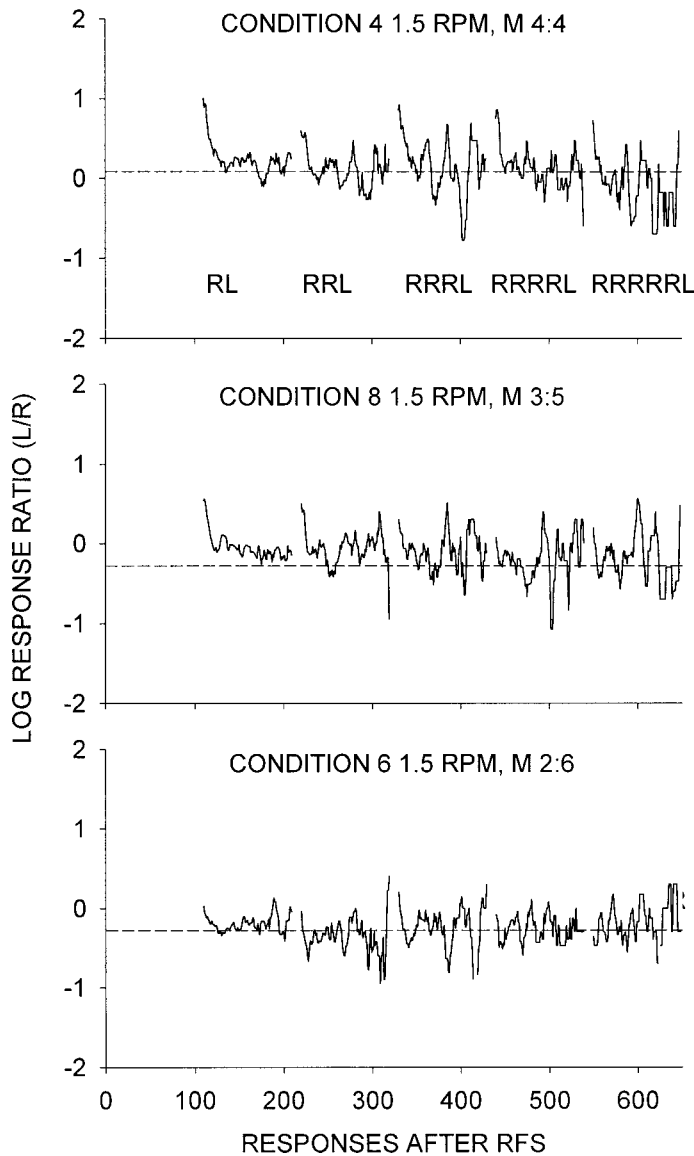


Fig. 11. Experiment 2. Preference pulses after reinforcers on the two alternatives following sequences of right-key reinforcers discontinued by a left-key reinforcer in Conditions 4, 8, and 6. The dashed lines show sessional mean log response ratios. The data were averaged across the 6 pigeons.

levels with reinforcer sequence were similar across conditions with different magnitude ratios.

Figures 11 and 12 show log response ratios for the first 100 responses after *discontinuations* of series of right-key reinforcers by a left-key reinforcer, and series of left-key reinforcers by a right-key reinforcer, respectively, for the same set of conditions as analyzed in Figure 10. Thus, in Figure 11 (lower two panels)

sequences were discontinued by smaller-magnitude reinforcers, whereas in Figure 12 sequences were discontinued by larger-magnitude reinforcers. The important result is that log response ratios following all discontinuations fell close to the mean levels for conditions. Thus the baseline increases shown in Figure 10 across same-alternative reinforcers were substantially attenuated by single reinforcers from the other alternative. This find-



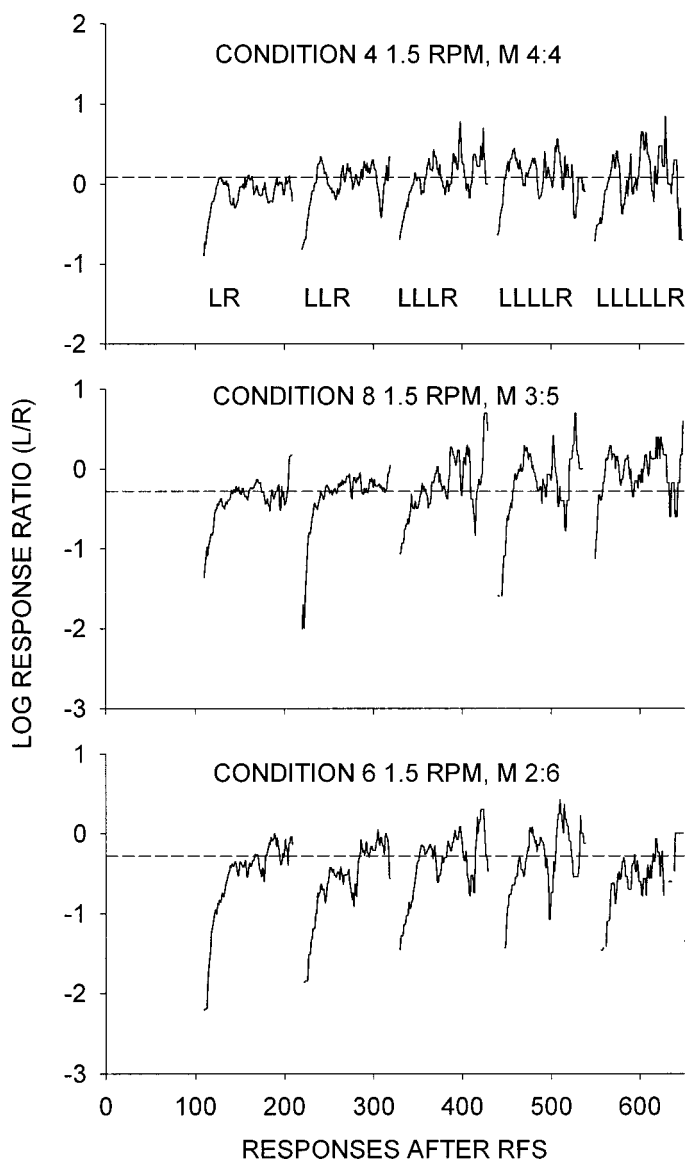


Fig. 12. Experiment 2. Preference pulses after reinforcers on the two alternatives following sequences of left-key reinforcers discontinued by a right-key reinforcer in Conditions 4, 8, and 6. The dashed lines show sessional mean log response ratios. The data were averaged across the 6 pigeons.

ing is the local representation of the general finding (Davison & Baum, 2000, 2002; Landon & Davison, 2001) that response ratios between reinforcers are brought close to sessional means by single discontinuations of reinforcer sequences. Figures 11 and 12 also suggest that initial preference following a discontinuation was usually unaffected by the number of prior same-alternative reinforcers. A decrease in initial preference was evident

for the Magnitude-6 reinforcer in Condition 6, but no such trend was evident for the Magnitude-5 reinforcers in Condition 8 (Figure 12).

Because preferences rarely crossed indifference in Experiment 2, no analysis of crossover points like that in Figure 5 (lower panel) was possible. An analysis of the size of the immediate effects on preference after reinforcers was possible, however, and it appears

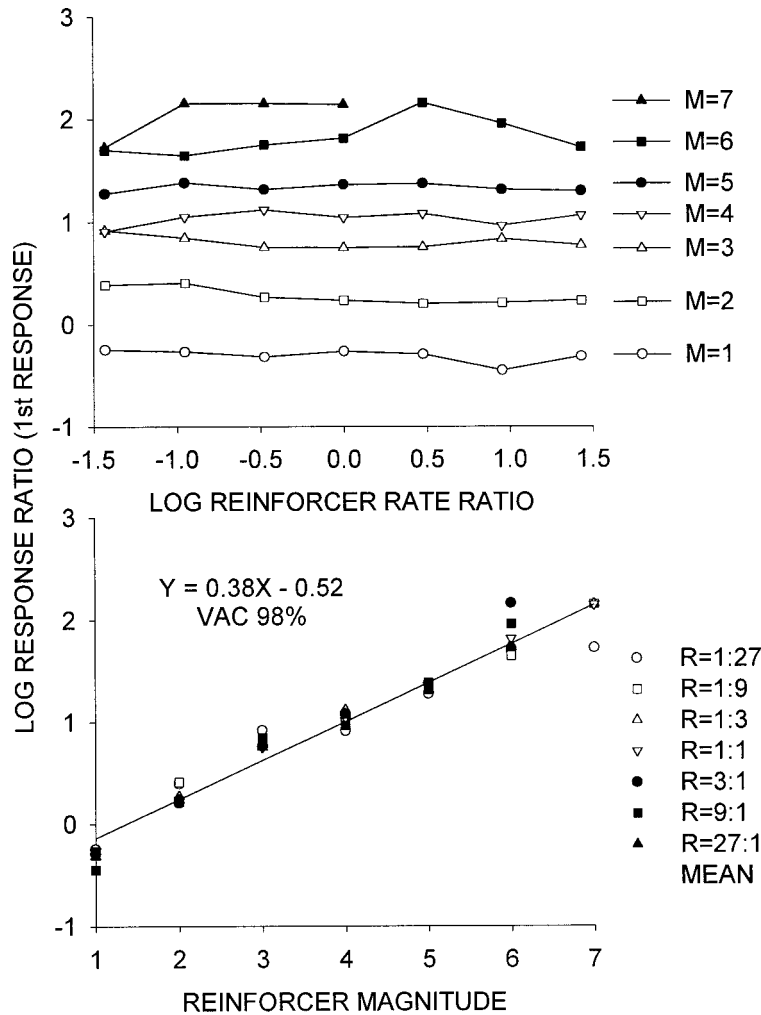


Fig. 13. Experiment 2. Log response ratios at the first response after a reinforcer plotted in two ways. Upper panel: As a function of the log reinforcer-rate ratio (that is, across components) separately for each reinforcer magnitude. The data for Magnitude 7, for instance, have been collapsed across the left key in Condition 5 and the right key in Condition 10. Lower panel: The same data plotted as a function of the reinforcer magnitude (that is, across conditions) separately for each reinforcer-rate ratio. The data were averaged across the 6 pigeons.

in Figure 13. In this figure, the effects of different-sized reinforcers have been collapsed across components (e.g., for Magnitudes 1 and 7, log response ratios toward the left key in Condition 5 have been combined with log response ratios toward the right key in Condition 10). In the top panel, log ratios of first postreinforcer responses are shown as a function of log reinforcer-rate ratios (i.e., components). Some points for Magnitude 7 are missing because the ratios were infinite. Magnitude effects on first-response preference were monotonically ordered, and the immediate

effect of a reinforcer depended on the size of the reinforcer. In the lower panel, the same log response ratios are plotted as a function of reinforcer magnitude. First-response log ratios increased with reinforcer magnitude with no differential effects of reinforcer-rate ratio. A linear regression on the data averaged across reinforcer ratios (Figure 13) gave a slope of 0.38 and an intercept of -0.52, with 98% of the variance accounted for. Thus a single 1.2-s reinforcer contributed slightly negatively to preference (-0.14), and subsequent 1.2-s reinforcers contributed a

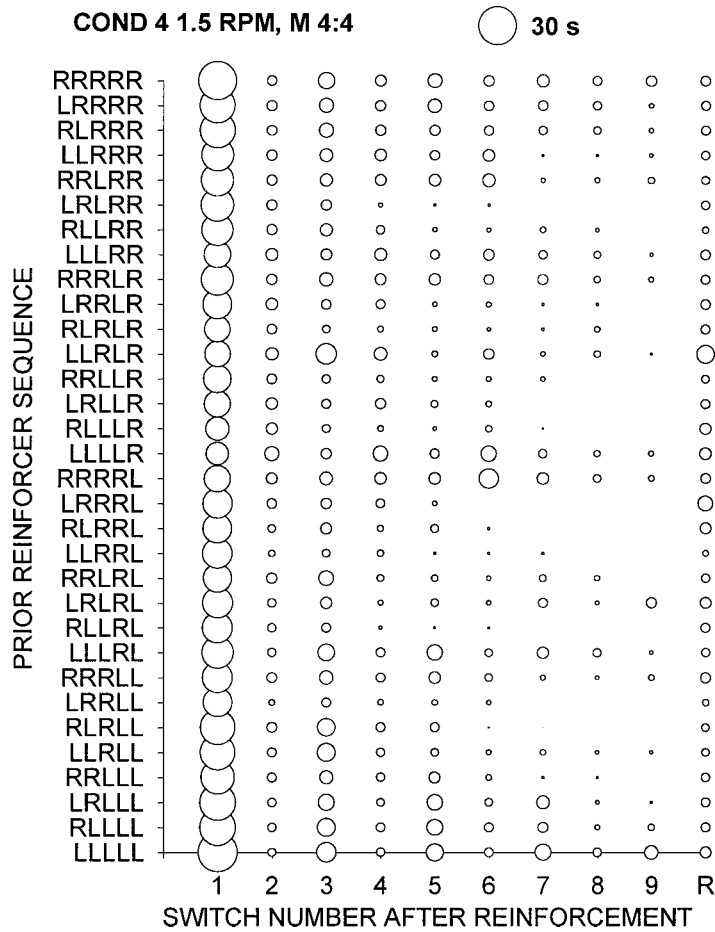


Fig. 14. Experiment 2. Bubble plots of successive visit durations (the diameter of the circles according to the key at the top of the figure) in seconds in Condition 4 (reinforcer magnitudes of 4 and 4) as a function of the prior sequence of reinforcers obtained. Visits that were truncated by reinforcers were omitted. The data are averages of the geometric means for each of the 6 pigeons. The data above R on the X axis show the average of the remaining switches.

constant additive amount (0.38) to preference.

Figures 14 and 15 show geometric mean visit durations (in seconds) and lengths (in responses) following all sequences of five preceding reinforcer locations for Condition 4, equal reinforcer magnitudes. In these figures, the size of the visit is denoted by the diameter of the symbols according to the key shown at the top of each figure. The first column of symbols shows the visits before the first switch following the last reinforcer (postreinforcer visits). The figures show that visit durations and lengths were generally longest just after a reinforcer and generally short thereafter. Reinforcer sequence had some effect, how-

ever, because more homogeneous sequences produced the longest visits, discontinuations (a sequence of reinforcers on one alternative followed by a single reinforcer on the other) produced the shortest visits (this was more evident in visit lengths in Figure 15 than in visit durations in Figure 14), and mixed sequences produced intermediate lengths. A summary might be that visit durations and lengths were affected by the last two reinforcers, and perhaps by the last three. First visits after reinforcers were generally, though not invariably, toward the just-reinforced alternative; hence, subsequent odd-numbered visits were also to the just-reinforced alternative. These were often longer than the intervening



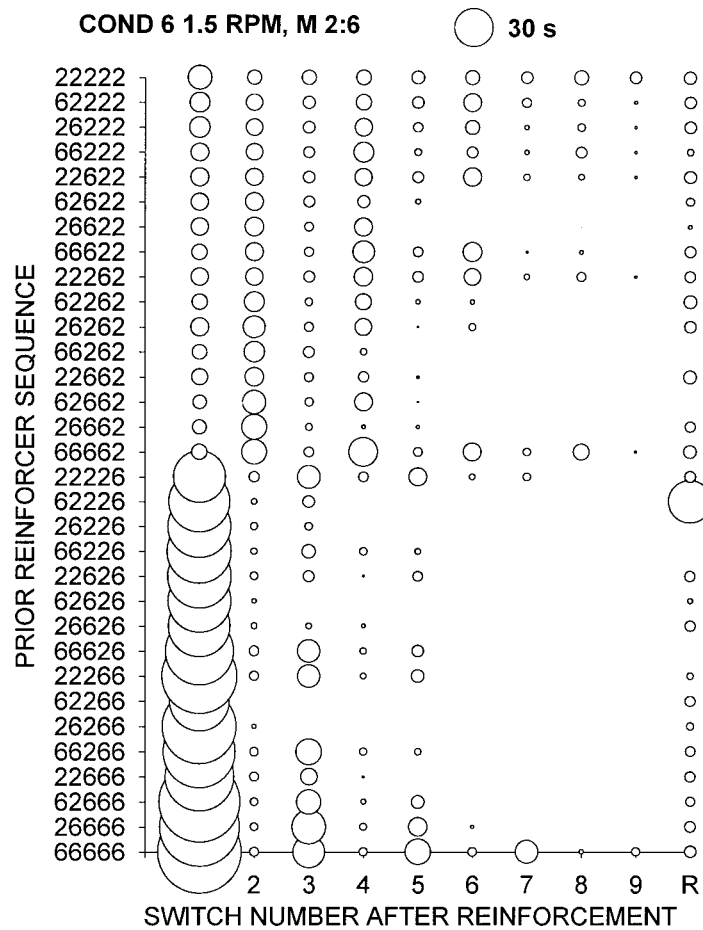


Fig. 16. Experiment 2. Bubble plots of successive visit durations (the diameter of the circles according to the key at the top of the figure) in seconds in Condition 6 (reinforcer magnitudes of 2 and 6) as a function of the prior sequence of reinforcers obtained. Visits that were truncated by reinforcers were omitted. The data are averages of the geometric means for each of the 6 pigeons. The data above R on the X axis show the average of the remaining switches.

Many of their findings were systematically replicated here when reinforcer-magnitude ratios changed unpredictably between unsignaled components (Experiment 1). For instance, sensitivity to reinforcer magnitude increased with increasing numbers of reinforcers in components (Figure 1; cf. Davison & Baum, Figure 17), but the sensitivity achieved after nine reinforcers in a component (0.22 to 0.31 for 6 reinforcers per minute in Figure 1) was less than that obtained at the same point in components when reinforcer rates were varied. This difference in sensitivity between reinforcer rate and magnitude is similar in direction to that found in steady-state experimentation (Schneider,

1973; Todorov, 1973). Although overall reinforcer rate had no effect on sensitivity to reinforcer-magnitude ratio in the current component, it affected sensitivity to reinforcer-magnitude ratio in the previous component (Figure 1). At 1.5 reinforcers per minute, sensitivity to the previous-component reinforcer-magnitude ratio fell with successive reinforcers in a similar fashion to the decline seen with reinforcer rate. But at 6 reinforcers per minute, sensitivity to the previous-component magnitude ratio remained about constant throughout the next component. This finding needs explanation, and it will at some stage inform theorizing about choice in this situation.

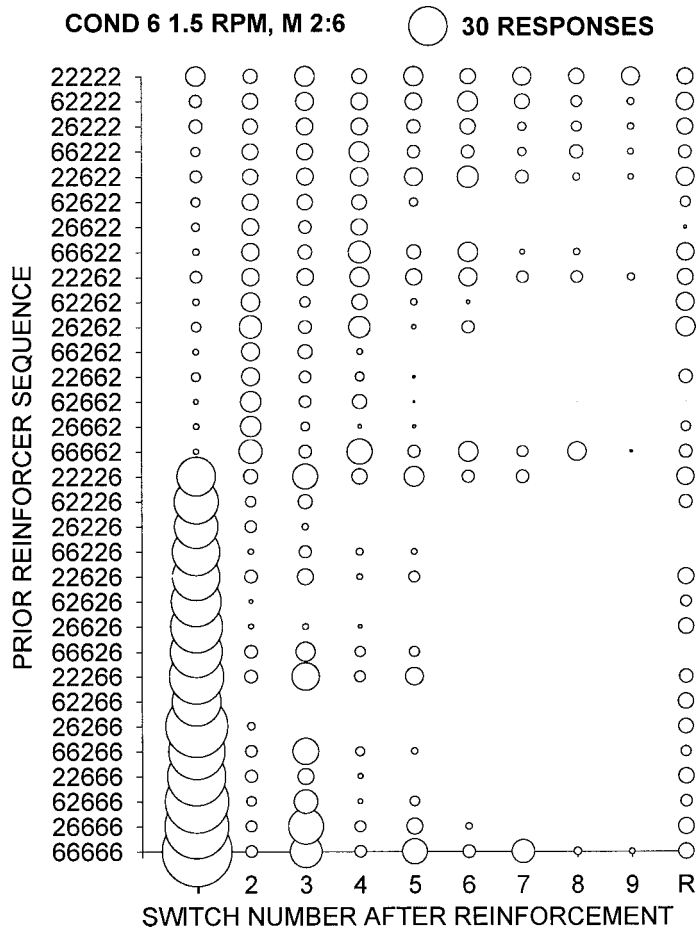


Fig. 17. Experiment 2. Bubble plots of successive visit durations (the diameter of the circles according to the key at the top of the figure) in numbers of responses in Condition 6 (reinforcer magnitudes of 2 and 6) as a function of the prior sequence of reinforcers obtained. Visits that were truncated by reinforcers were omitted. The data are averages of the geometric means for each of the 6 pigeons. The data above R on the X axis show the average of the remaining switches.

A further finding that needs explanation is that sensitivity to reinforcer magnitude in Experiment 2, in which a single magnitude ratio was maintained across components within conditions, was considerably higher (about 1.0) than the sensitivities found in Experiment 1. It appears that varying the controlling variable—either reinforcer-magnitude or reinforcer-rate ratio—between components leads to lower asymptotic sensitivity within components than the sensitivity measured in the steady state. Sensitivity to reinforcer-magnitude ratio in Experiment 2, however, was considerably larger than reported steady-state sensitivities (Davison & Hogsden, 1984; Schneider, 1973; Todorov, 1973), and at a lev-

el commensurate with steady-state sensitivity to reinforcer-rate ratio (Landon et al., 2002). This could be a result of using a series of short reinforcer presentations compared with a single long-duration reinforcer. Further work on reinforcer-magnitude variation is required.

A second surprising finding from Experiment 2 was that sensitivity to reinforcer-magnitude ratio was lower before the first reinforcer in a component rather than later in the component (Figures 6 and 7). Because magnitude ratios were constant across components within conditions, no ambiguity existed as to which alternative provided the greater reinforcer. Why, then, should magni-

tude sensitivity be lower before the first component reinforcer? The model suggested by Davison and Baum (2000, 2002) would imply that the accumulated reinforcers mixed between the alternatives during the 10-s blackout. Landon and Davison (2001) and Landon et al. (2002), however, presented data showing that such mixing should be toward the sessional mean, and here the sessional mean magnitude ratio remained constant and non-zero in all conditions of Experiment 2 except Condition 4. Alternatively, initial sensitivity in components is more affected by the sessional reinforcer-rate ratio (always 1.0 in Experiment 2), implying that reinforcer accumulation concatenates magnitude and rate ratios.

Figure 7 highlights a third unexpected finding. Estimated sensitivity to reinforcer-magnitude ratio, both at the start of components and at the end of components, was itself affected by the reinforcer-magnitude ratio—choice was more sensitive to magnitude differentials when the differentials were greater. A similar effect has been reported before in a number of areas of choice research. Davison and Hogsden (1984), using reinforcer durations, found that sensitivity to duration ratio varied when durations were varied. Keeping one duration at 3 s, they varied the other from 1 s to 10 s across conditions, finding that sensitivity increased as duration increased. Logue and Chavarro (1987) found that sensitivity to reinforcer duration fell when the absolute reinforcer durations were increased in conditions with constant reinforcer-duration ratios (in other words, sensitivity increased as the smaller of the two durations was decreased—as found here). Similar effects have been found with other controlling variables. For instance, both Duncan and Fantino (1970) and Logue and Chavarro found that sensitivity to reinforcer-delay ratio increased as absolute delays (and the smaller delay) increased. Converting reinforcer delay to reinforcer immediacy, the reciprocal of delay, sensitivity increased as the smaller reinforcer immediacy decreased. Finally, sensitivity to reinforcer-rate ratio increases as overall reinforcer rate is increased (Alsop & Elliffe, 1988; Davison & Baum, 2000; Elliffe & Alsop, 1996). We can offer no simple generalization that can encompass all these results.

The above discussion of increased sensitiv-

ity to reinforcer magnitude with more extreme magnitude ratios raises the possibility that sensitivity to magnitude differentials can be enhanced by concomitant reinforcer-rate variation. Landon et al. (2003), in a steady-state procedure, reported sensitivities to reinforcer magnitude averaging 0.76, with no suggestion that sensitivities changed with magnitude ratio (their Figure 1). Experiment 2 varied reinforcer magnitudes across conditions, but additionally varied reinforcer-rate ratios within sessions. Here, there were similar end-of-component reinforcer-magnitude sensitivities (about 0.7) when log magnitude ratios were close to 0, but often much larger values when they were distant from 0 (Figure 7). Landon et al. kept the reinforcer rates on the alternatives equal throughout. Would their results have been different had they used unequal reinforcer rates, or is the effect we have found dependent on reinforcer-rate ratio variation? Davison and Hogsden (1984), who reported that sensitivities to reinforcer-magnitude ratios in a steady-state procedure increased with magnitude ratio, used equal reinforcer frequencies throughout. The available evidence, thus, currently fails to converge on either factor, inviting further research.

Figure 7 also shows an invariance: Sensitivity to the current and previous component reinforcer-rate ratio was unaffected by reinforcer-magnitude ratio. This result corresponds to a similar steady-state finding (McLean & Blampied, 2001). Another invariance appeared in Experiment 1: Sensitivity to reinforcer-magnitude ratio was unaffected by overall reinforcer rate. Steady-state research, however, previously showed that increasing overall reinforcer rate decreases sensitivity to reinforcer-magnitude differentials (Davison, 1988).

Changes in sensitivity to reinforcer-rate ratio with successive component reinforcers in Experiment 2 (Figure 6, Condition 4) resembled those reported by Davison and Baum (2000, 2002). Thus the present way of arranging reinforcer magnitudes left sensitivity to reinforcer-rate ratio unaffected.

Landon et al. (2002, Figure 5) showed that reinforcers were followed by a relatively short period of enhanced preference toward the alternative at which the reinforcer had been obtained (a preference pulse). Unpublished

analyses also have shown their existence in the data reported by Davison and Baum (2000, 2002). They also were found here (Figures 2, 3, 4, 8, and 9), and Figure 8 shows preference pulses resembling those we have calculated from previous data sets in which reinforcer duration was the same for both alternatives. In the present experiments, the size and duration of preference pulses increased as reinforcer magnitude increased (Figures 5 and 9). The shapes of the preference pulses, however, differed between Experiments 1 and 2. In Experiment 1, preference frequently switched from one alternative to the other within 40 responses after a reinforcer, whereas in Experiment 2 no such switches occurred (Figures 2, 3, and 4; the best comparison is Figure 4, which provided the same overall reinforcer rate as Experiment 2). What caused this difference? In Experiment 1, magnitude ratios were varying between components, whereas in Experiment 2, reinforcer-rate ratios were varying between components. The latter might be expected to reduce the frequency of changeovers because, for example, reinforcer-rate ratios of 27:1 and 1:27 with an overall 1.5 reinforcers per minute scheduled reinforcers on the average once every 41.5 s on the higher-rate alternative and once every 1,120 s on the lower-rate alternative. Across components, mean interreinforcer intervals varied between 41.5 s and 1,120 s on both alternatives, thus producing some long sequences of reinforcers continuing on one alternative. In Experiment 1, however, reinforcers occurred on the average every 80 s on both alternatives throughout Condition 3 (the same overall reinforcer rate as in Experiment 2), likely producing a higher frequency of short runs, and a lower frequency of long runs of reinforcers, on each alternative. The higher likelihood that the next reinforcer will occur on a different alternative from the previous reinforcer might explain the higher likelihood of a switch in responding in Experiment 1.

The present and other research on local effects of reinforcers in concurrent performance (Davison & Baum, 2000, 2002; Landon & Davison, 2001; Landon et al., 2002) reveals more and more that reinforcer sequences are a potent controlling variable for both mean preference between reinforcers and for preference pulses and visits following

reinforcers. Reinforcer sequence might translate into a local reinforcer-rate ratio, perhaps with more recent reinforcers weighted more heavily than more temporally distant reinforcers. Davison and Baum (2002) and Landon et al. (2002) suggested such a model, with both shorter- and longer-term decrements of recent reinforcer effects, though Landon et al. (2003) found some problems with it. We do not attempt a model of the present data here for a number of reasons. First, we still have insufficient data to develop an effective model. In particular, we need more data on effects of sequences of reinforcers both in the Belke and Heyman (1994) procedure and in the equivalent steady-state situation. Second, we are still unsure about the level at which we should be modeling—mean response rate between reinforcers or the duration of visits to alternatives or preference pulses? Third, we are unsure whether it will be most appropriate to model statically or dynamically. If the former can be achieved, there will be a considerable advantage in simplicity, but it may be at the expense of understanding the continuous exchange between organism and environment (Baum, 1973).

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## APPENDIX

Figures showing selected data analyses for each individual pigeon.

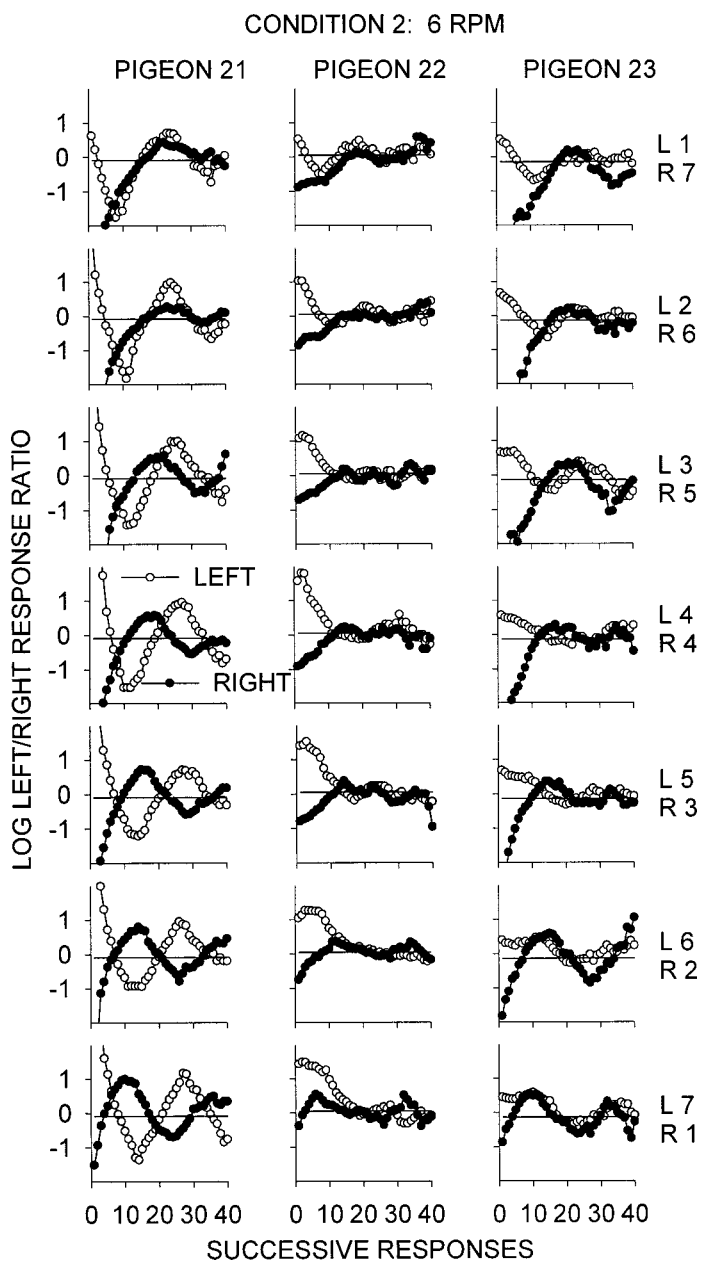


Fig. A1. Experiment 1. Condition 2 (six reinforcers per minute). Log left/right response ratios at each response up to 40 responses after left- and right-key reinforcers for Pigeons 21 to 23. The data are shown separately for all seven reinforcer-magnitude ratios.

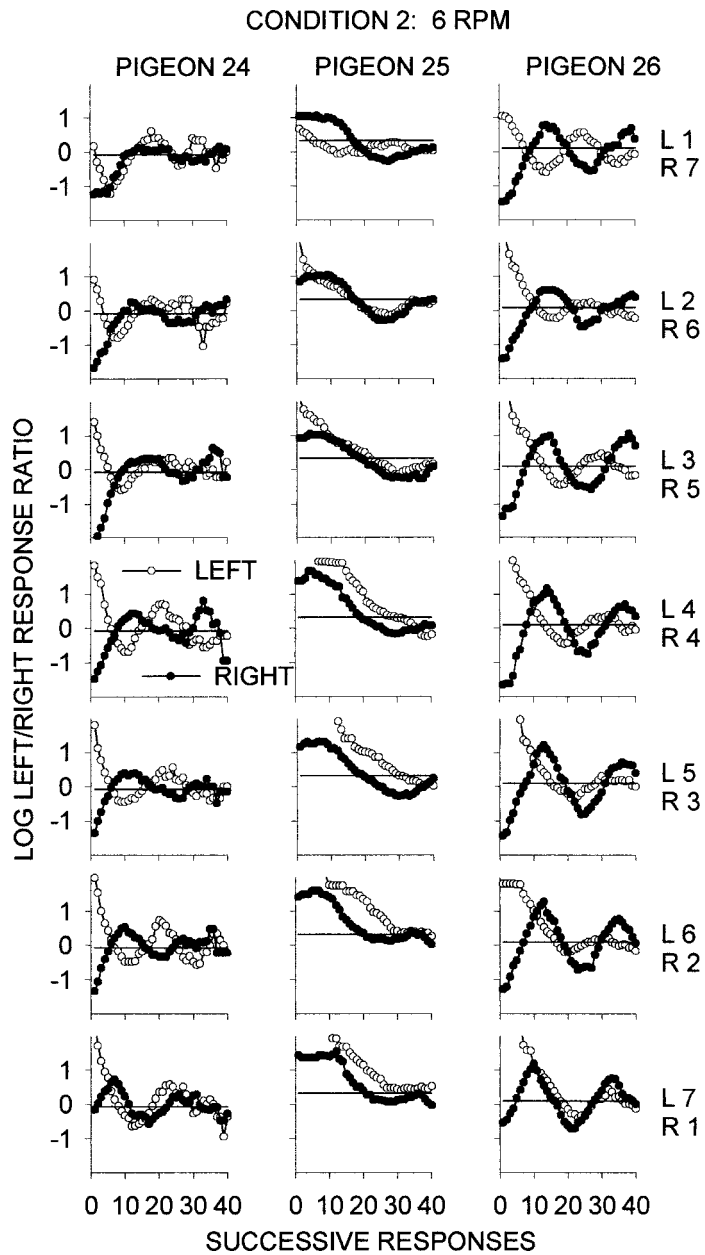


Fig. A2. Experiment 1. Condition 2 (six reinforcers per minute). Log left/right response ratios at each response up to 40 responses after left- and right-key reinforcers for Pigeons 24 to 26. The data are shown separately for all seven reinforcer-magnitude ratios.

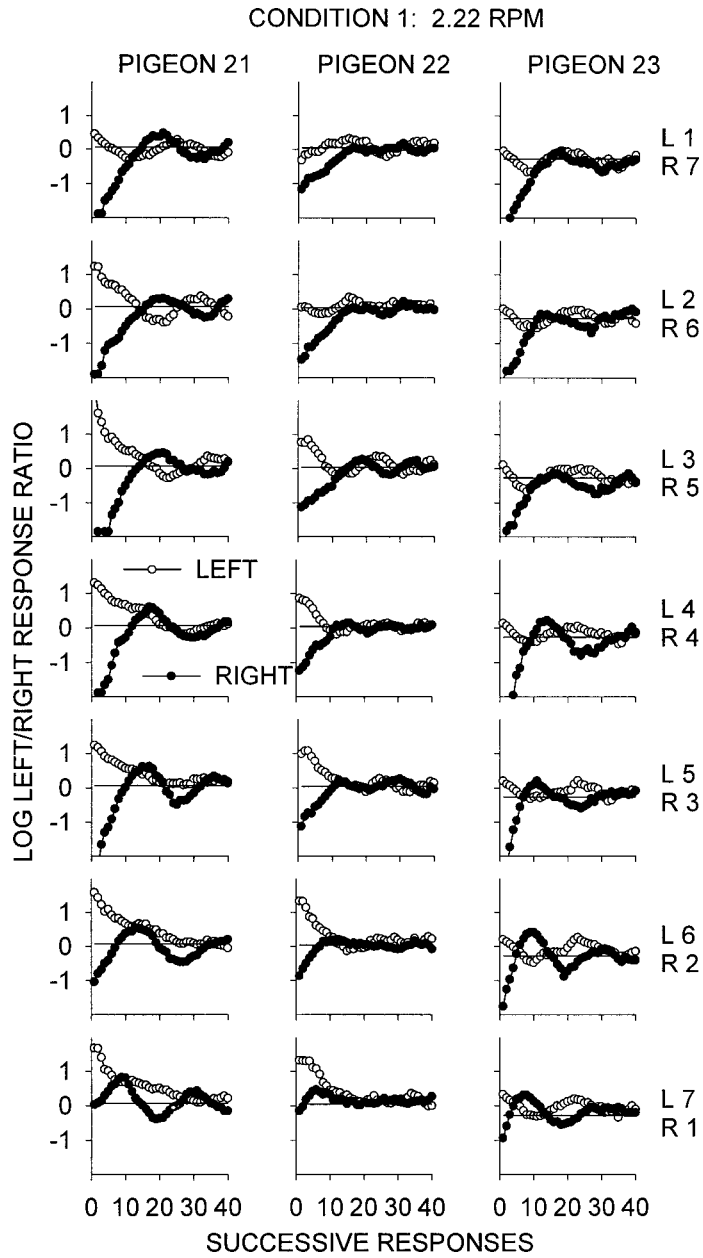


Fig. A3. Experiment 1. Condition 1 (2.22 reinforcers per minute). Log left/right response ratios at each response up to 40 responses after left- and right-key reinforcers for Pigeons 21 to 23. The data are shown separately for all seven reinforcer-magnitude ratios.

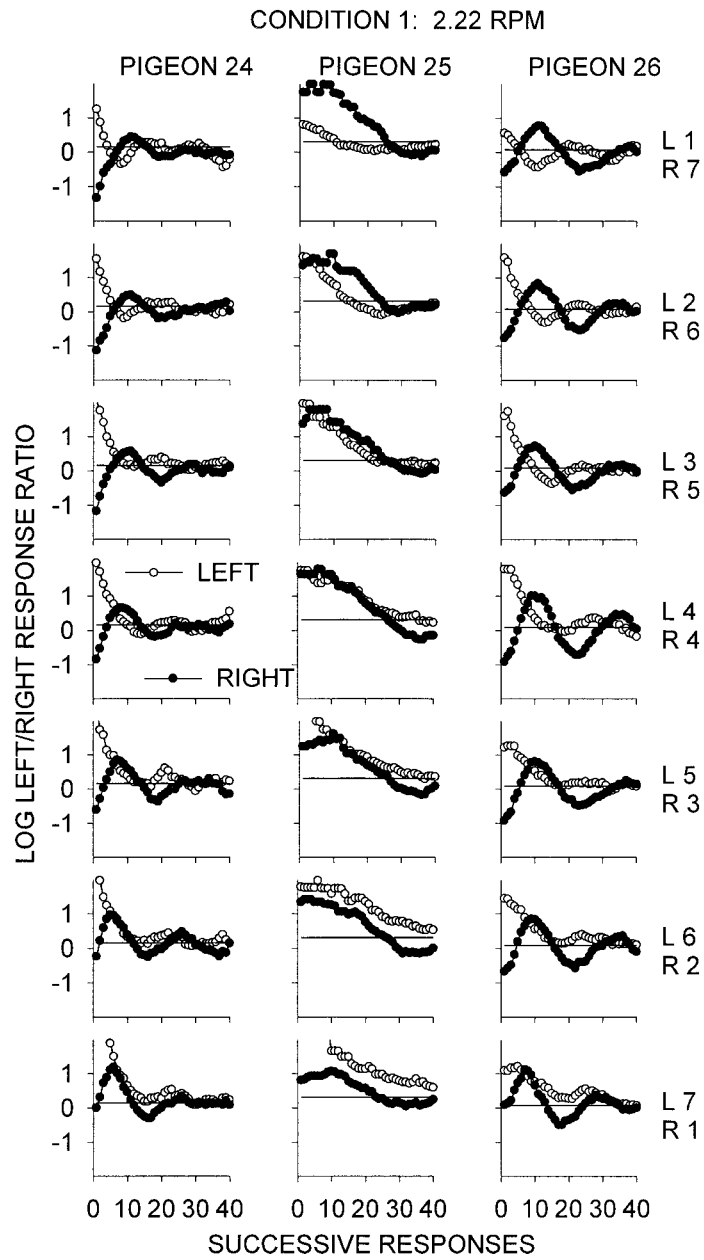


Fig. A4. Experiment 1. Condition 1 (2.22 reinforcers per minute). Log left/right response ratios at each response up to 40 responses after left- and right-key reinforcers for Pigeons 24 to 26. The data are shown separately for all seven reinforcer-magnitude ratios.

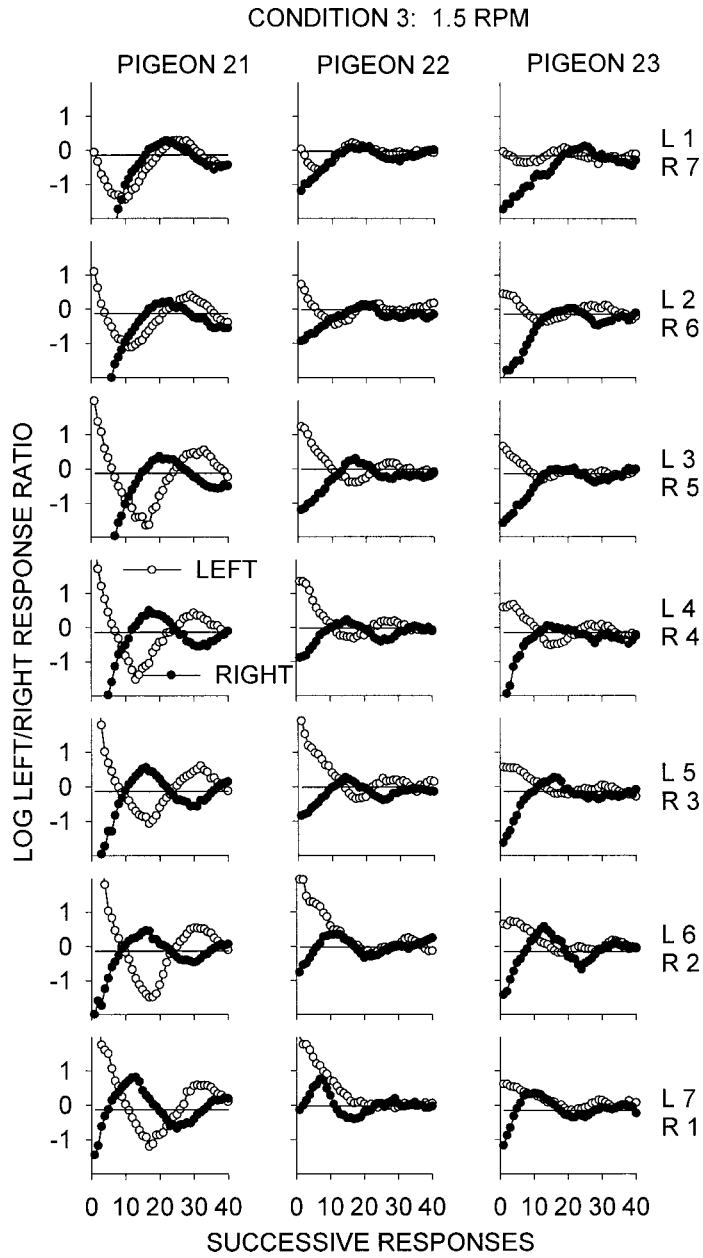


Fig. A5. Experiment 1. Condition 3 (1.5 reinforcers per minute). Log left/right response ratios at each response up to 40 responses after left- and right-key reinforcers for Pigeons 21 to 23. The data are shown separately for all seven reinforcer-magnitude ratios.

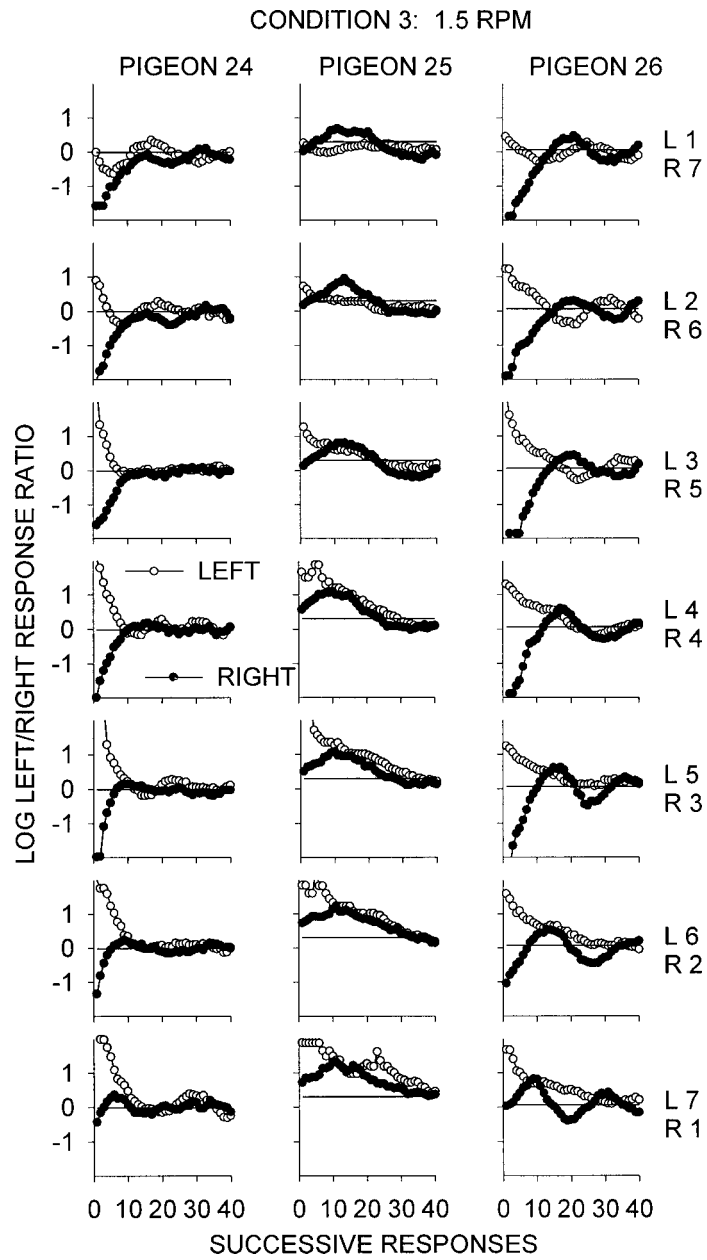


Fig. A6. Experiment 1. Condition 3 (1.5 reinforcers per minute). Log left/right response ratios at each response up to 40 responses after left- and right-key reinforcers for Pigeons 24 to 26. The data are shown separately for all seven reinforcer-magnitude ratios.

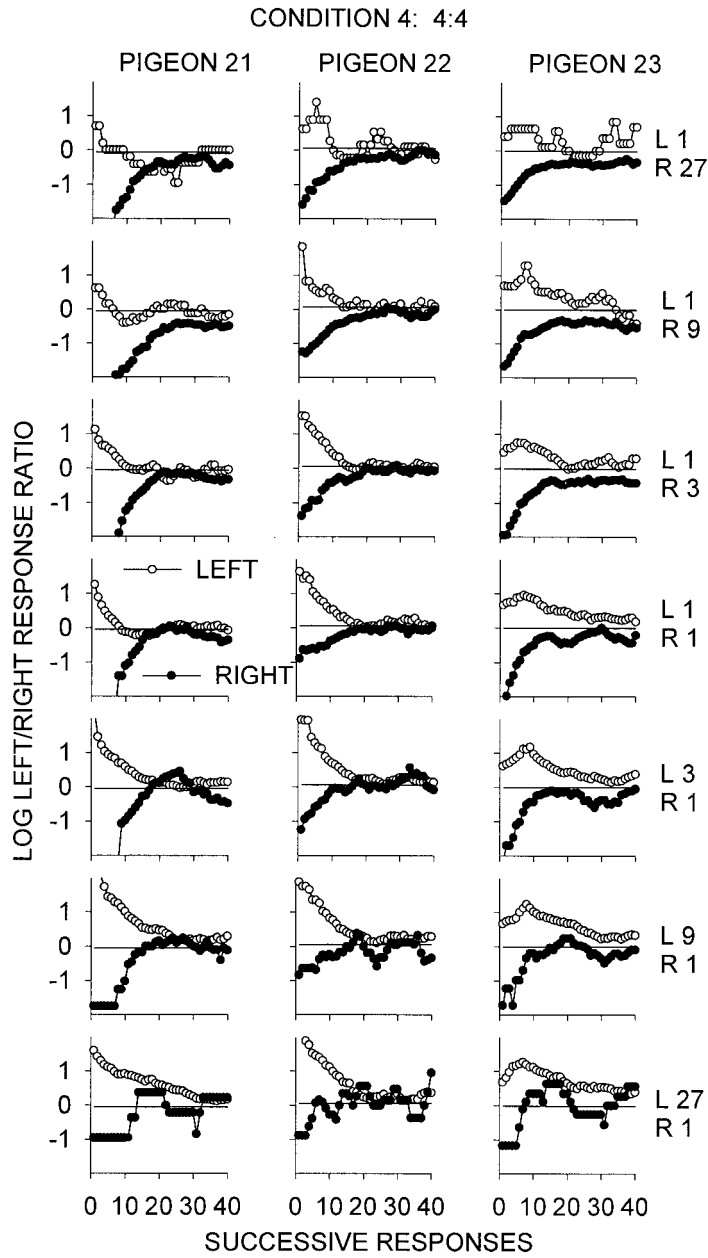


Fig. A7. Experiment 2. Condition 4 (both alternatives Magnitude-4 reinforcers). Log response ratios at each response up to 40 responses after left- and right-key reinforcers for Pigeons 21 to 23. The data are shown separately for all seven reinforcer-rate ratios.



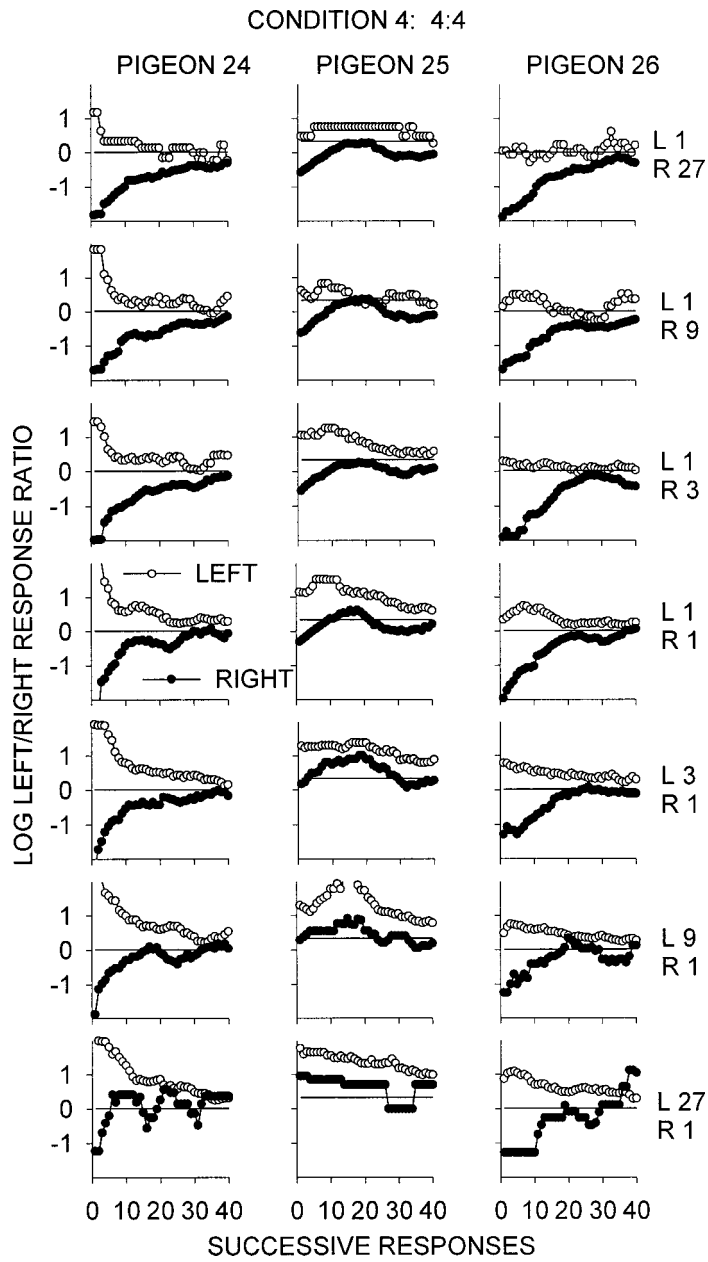


Fig. A8. Experiment 2. Condition 4 (both alternatives Magnitude-4 reinforcers). Log response ratios at each response up to 40 responses after left- and right-key reinforcers for Pigeons 24 to 26. The data are shown separately for all seven reinforcer-rate ratios.

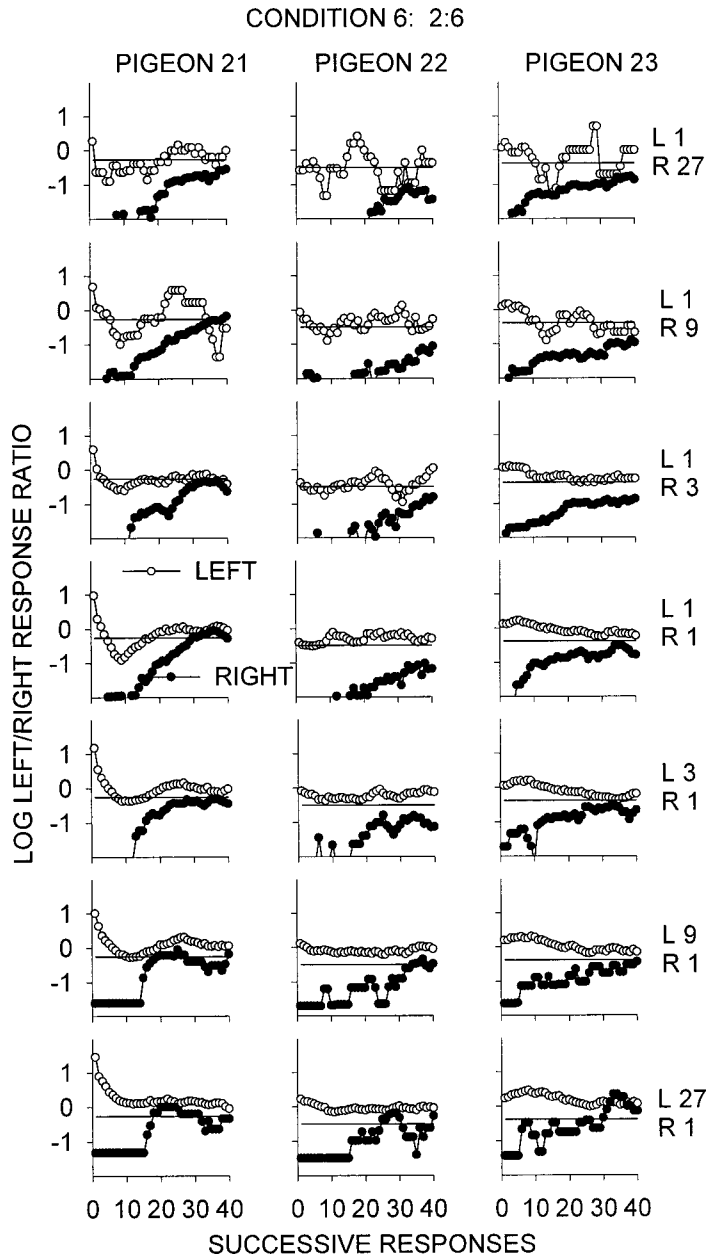


Fig. A9. Experiment 2. Condition 6 (left-key Magnitude 2, right-key Magnitude 6). Log response ratios at each response up to 40 responses after left- and right-key reinforcers for Pigeons 21 to 23. The data are shown separately for all seven reinforcer-rate ratios.

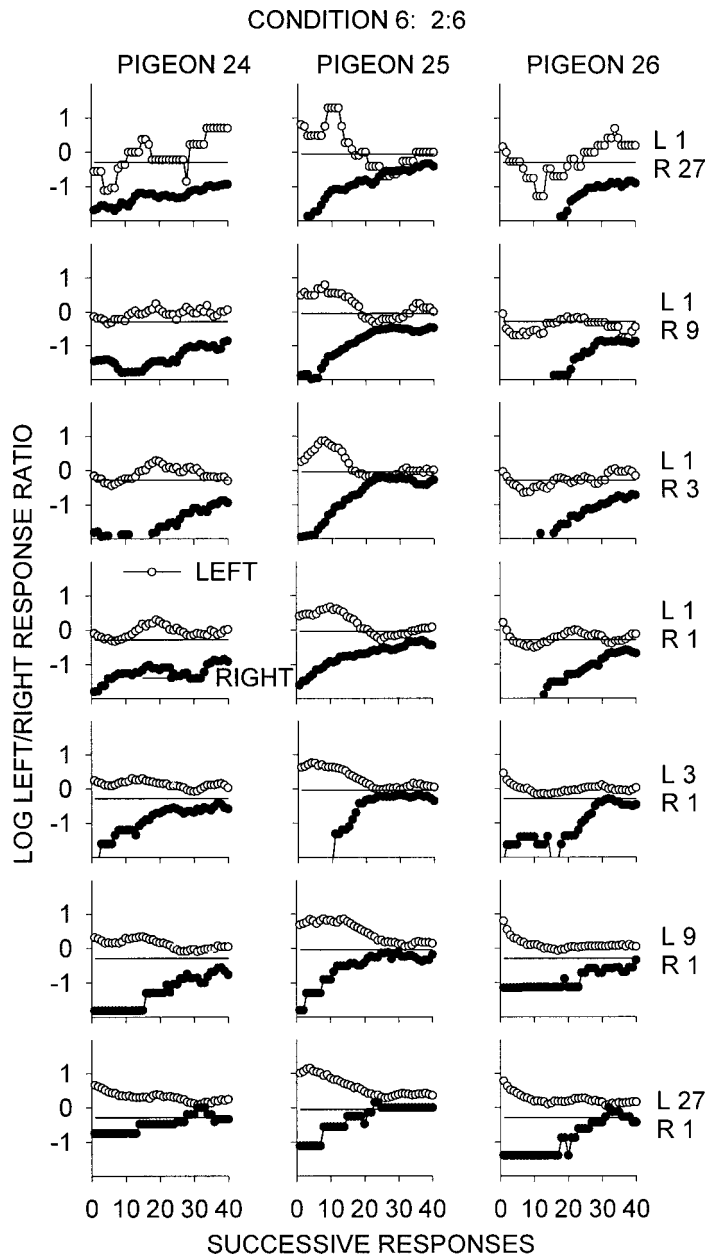


Fig. A10. Experiment 2. Condition 6 (left-key Magnitude 2, right-key Magnitude 6). Log response ratios at each response up to 40 responses after left- and right-key reinforcers for Pigeons 24 to 26. The data are shown separately for all seven reinforcer-rate ratios.