CHOICE IN A VARIABLE ENVIRONMENT: EFFECTS OF BLACKOUT DURATION AND EXTINCTION BETWEEN COMPONENTS

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Pigeons were trained in a procedure in which sessions included seven four- or 10-reinforcer components, each providing a different reinforcer ratio that ranged from 27:1 to 1:27. The components were arranged in random order, and no signals differentiated the component reinforcer ratios. Each condition lasted 50 sessions, and the data from the last 35 sessions were analyzed. Previous results using 10-s blackouts between components showed some carryover of preference from one component to the next, and this effect was investigated in Experiment 1 by varying blackout duration from 1 s to 120 s. The amount of carryover decreased monotonically as the blackout duration was lengthened. Preference also decreased between reinforcers within components, suggesting that preference change during blackout might follow the same function as preference change between reinforcers. Experiment 2 was designed to measure preference change between components more directly and to relate this to preference change during blackout. In two conditions a 60-s blackout occurred between components, and in two other conditions a 60-s period of unsignaled extinction occurred between components. Preference during the extinction period progressively fell toward indifference, and the level of preference following extinction was much the same as that following blackout. Although these results are consistent with Davison and Baum's (2000) theory of the effects of reinforcers on local preference, other findings suggest that theory is incomplete: After a sequence of reinforcers from one alternative, some residual preference remained after 60 s of extinction or blackout, indicating the possibility of an additional longer term accumulation of reinforcer effects than originally suggested.

Key words: concurrent schedules, choice, carryover, blackout, extinction, key peck, pigeons

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Concurrent-schedule research has shown that choice, as measured by the allocation of time or responses, is controlled by, among other variables, the relative frequency of reinforcers obtained on the choice alternatives (e.g., Davison & McCarthy, 1988). In an earlier study of choice on concurrent variable-interval (VI) VI schedules, Davison and Baum (2000) noted that comparisons of previous research reports suggest that the speed at which choice behavior on concurrent VI VI schedules adapts to reinforcement changes depends on the frequency with which an animal's environment changed. In other words,

the speed with which animals change their behavior might not be an organismic constant, but might depend on an organism's environment. In traditional steady-state concurrent-schedule research, stability is usually attained in 15 to 30 1-hr sessions, whereas when schedules may change every session, asymptotic performance occurs in as few as one to three sessions (Hunter & Davison, 1985; Schofield & Davison, 1997). On the basis of this observation, we investigated whether adaptation would be even faster if the concurrent schedules changed within a session, and whether the frequency of change of reinforcer ratios within a session further affected the speed at which response ratios changed.

Within a session, Davison and Baum (2000) arranged seven different reinforcer ratios in components that were separated by 10-s blackouts but that provided no signal for which component was in effect (Belke & Heyman, 1994). We varied the frequency of change of reinforcer ratios by varying the number of reinforcers delivered in components from four to 12. Performance stabilized after only five to eight component reinforc-

ers, much faster than in both steady-state procedures and procedures that change reinforcer ratios once per session. However, we found no evidence that frequency of change within session affected the speed of change of response ratios. We also reported that response ratios changed faster with successive reinforcers in components when the overall reinforcer rate was higher. Subsequent research by Landon and Davison (2001), using the same general procedure, showed that variation in the range of the reinforcer ratios, rather than in the frequency of changing the reinforcer ratios, affected the speed of adaptation: The greater the range of reinforcer ratios across components, the faster the adaptation.

Davison and Baum (2000) also found some carryover in choice from previous components to current components, and the amount of carryover decreased as more reinforcers were obtained in the current component. To do this analysis, we carried out multiple linear regressions in which the dependent variable was the current-component response ratio (logarithmically transformed; ''log'' hereafter) measured between two successive reinforcers, and the independent variables were the current-component log reinforcer ratio and the previous-component log reinforcer ratio. These regressions were based on the generalized matching law (Baum, 1974), and provide estimates of sensitivity values to the current-component and the previous-component reinforcer ratios. The equation used was

$$\log\left(\frac{B_{li}}{B_{ri}}\right) = a_{pi}\log\left(\frac{R_{lp}}{R_{rp}}\right) + a_{ci}\log\left(\frac{R_{lc}}{R_{rc}}\right)$$
$$+ \log c, \tag{1}$$

where B and R refer to responses and arranged component reinforcers, l and r refer to the left and right alternatives, p and c refer to the previous and current components, and i is the reinforcer order in a component ($i = 0$, prior to the first reinforcer, to one less than the number of reinforcers per component).

For the response ratios obtained between successive reinforcers, we found that, as more reinforcers were delivered in a component, sensitivity to the current-component reinforcer ratio (a_{ci}) progressively increased, and sensitivity to the previous-component reinforcer ratio (a_{pi}) progressively decreased. That is, as

more reinforcers were delivered in components, control over response allocation by the current component increased and control by the previous component decreased. Davison and Baum (2000) found no effect of frequency of component change on the amount of carryover from the previous component to the current component, but Landon and Davison (2001) found evidence of increased amounts of carryover when the component reinforcer ratios varied over a greater range. The interpretation of the latter finding, however, is uncertain because increasing reinforcer-ratio range produced more extreme response ratios in components; the amount of carryover might just be a constant proportion of the response ratio attained in the previous component.

The 10-s blackout, which was a highly discriminable event that signaled an unpredictable change in reinforcer ratio, nevertheless failed to eliminate the effects of the reinforcers obtained in a previous component. Although the blackout signaled that a new reinforcer ratio was about to commence, the response ratio at the beginning of a new component still reflected to some extent the response ratio that prevailed at the end of the previous component. Davison and Baum (2000) accommodated this carryover in a quantitative model of the performance. The model assumed that each reinforcer added to two accumulators (one for each alternative), and that two further processes occurred during the time when no reinforcers occurred. These two processes were (a) the gradual loss of reinforcers from both accumulators during periods of nonreinforcement, and (b) the gradual confusion during periods of nonreinforcement between reinforcers in the two accumulators. The first process allows the first reinforcers delivered following intercomponent blackouts to have comparatively large effects on behavior allocation. It also implies that behavior allocation should change faster at the start of each component when blackout durations are longer, because fewer reinforcers would remain in the accumulators. The second process should culminate in the equality of accumulations if sufficient time passes without a reinforcer. Thus, the second process implies less carryover between components with longer intercomponent blackouts. Both these processes were assumed to

occur during intercomponent blackouts and between reinforcers within components.

The first experiment reported here investigated behavior allocation within components and carryover between components as a function of intercomponent blackout durations ranging from 1 to 120 s. If longer blackouts cause the response ratio to change faster at the beginning of a new component and to be less affected by the prior component, such findings would support our quantitative model. We also varied number of reinforcers per component in order to look further for any effects of frequency of change in reinforcer ratio. The second experiment, using the same subjects, was designed to measure change in preference continuously during periods between components. Instead of blackouts, we arranged a 60-s period of unsignaled extinction between components and measured response ratio during this period. If the response ratios following this period of extinction resemble those following a blackout of the same duration, such a finding would support our assumption that the processes that occur between reinforcers within components are the same ones that occur during the intercomponent blackout.

EXPERIMENT 1

METHOD

Subjects

Six homing pigeons, numbered 91 to 96, were maintained at 85% ± 15 g of their free-feeding body weights by supplementary feeding of mixed grains following experimental sessions. Water and grit were available at all times. These subjects were used previously by Davison and Baum (2000) and subsequently in similar procedures.

Apparatus

The subjects 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 could be illuminated yellow, green, or red with

Table 1

Sequence of experimental conditions, number of reinforcers per component, and the blackout duration between components. The overall arranged rate of reinforcers was 6 per minute in Experiment 1 and 2.22 per minute in Experiment 2. In conditions with 4 reinforcers per component, each component was presented twice per session. The data from Conditions 8 and 9 were previously reported by Davison and Baum (2000).

Con-dition	Reinforcers per component	Inter-component blackout(s)	Inter-component extinction(s)
Experiment 1: COD 2 s, 6 reinforcers per minute			
8	12	10	
9	4	10	
10	4	30	
11	12	30	
12	4	1	
13	12	1	
14	4	120	
15	12	120	
Experiment 2: No COD, 2.22 reinforcers per minute			
22	4		60
23	10		60
24	4	60	
25	10	60	

light-emitting diodes situated behind the keys, and responses to illuminated keys exceeding about 0.1 N were counted as effective responses. A magazine aperture (40 mm by 40 mm) was located beneath the center key, 60 mm from the perch. During reinforcement, the keylights were extinguished, the aperture was illuminated, and the hopper, containing wheat, was raised for 2.5 s. The subjects could see and hear pigeons in other experiments, but no personnel entered the room while the experiments were in progress.

Procedure

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

Sessions were conducted daily commencing at 2:00 a.m. following lighting of the room at 1:00 a.m. The room lights were extinguished at 4:00 p.m. each day. The 6 subjects were studied in order with sessions lasting until a fixed number of reinforcers (see Table 1) had been collected or until 45 min had elapsed, whichever occurred first. 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

when 12 reinforcers per component were arranged and 14 components when four reinforcers per component were arranged. In the latter conditions, each of the basic seven components was first selected randomly, and then a second randomization of these components was arranged. All components lasted for the same fixed number of reinforcers (Table 1), which varied across conditions, and the components were separated by the blackout of both keys for a fixed period of time, as shown in Table 1. The arranged overall reinforcer rate was six per minute in each component, but the values of the schedules on the two keys changed randomly over the components, providing either seven or 14 different, unsignaled reinforcer ratios for the session depending on the condition. In all conditions, the reinforcer ratios in the seven components were 27:1, 9:1, 3:1, 1:1, 1:3, 1:9, and 1:27. 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 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.

RESULTS

Figure 1 shows the results of an analysis using Equation 1. The data used in this analysis were averaged across subjects. The results agree with our earlier findings (Davison & Baum, 2000) and those of Landon and Davison (2001) that sensitivity to the current-component reinforcer ratio (a_{ci}) increased progressively from close to zero prior to any reinforcer delivery in a component to between 0.6 and 0.8 after eight to 12 reinforcers. For four reinforcers per component, sensitivity increased monotonically to between 0.4 and 0.6 after three reinforcers. The number of reinforcers per component had no effect on sensitivity to the current reinforcer ratio; across individuals and component re-

inforcers, 41 of 96 differences were positive (sign test; $p > .05$).

Analysis of the effects of blackout duration across all component reinforcers showed a significant increase in sensitivity to the current-component reinforcer ratio with increasing duration across all blackout durations for both four and 12 reinforcers per component for the grouped data (nonparametric trend test, Ferguson, 1971; $z = 2.65$ and $z = 2.55$, respectively). Although these trends were the same for the individual subjects, only Birds 92 and 95 (four reinforcers per component) and Birds 92 and 94 (12 reinforcers per component) showed significant individual trends. A more detailed analysis of the individual data using Friedman analyses of variance showed that most of the change occurred between the 1-s and 10-s blackout durations, with significant increases for both the four and 12 reinforcers per component data (both $p < .05$). Thus, lengthening the blackout appeared to increase maximum sensitivity across components, at least between the 1-s and 10-s blackout durations.

Eighty of the 96 carryover sensitivities obtained using four reinforcers per component fell below the corresponding carryover sensitivities with 12 reinforcers per component (sign test; $p < .05$). Thus, regardless of blackout duration, 12 reinforcers per component produced more carryover than four reinforcers per component.

With both four and 12 reinforcers per component, sensitivity to the previous-component reinforcer ratio (a_{pi}) prior to the first reinforcer in a component fell monotonically with increasing blackout duration in the group data (Figure 1). Again, a more detailed analysis using individual data showed significant decreases in sensitivity both before (four and 12 reinforcers per component) and after (four reinforcers per component) the first reinforcer. Before the first reinforcer, the group decrease for four reinforcers per component was from 0.39 (1-s blackout) to 0.03 (120-s blackout), and for 12 reinforcers per component it was from 0.54 (1-s blackout) to 0.07 (120-s blackout). Beyond the first reinforcer, however, carryover sensitivity failed to vary significantly with blackout duration, because sensitivity quickly approached zero. Sensitivity to the previous-component reinforcer ratio continued for some time into the current
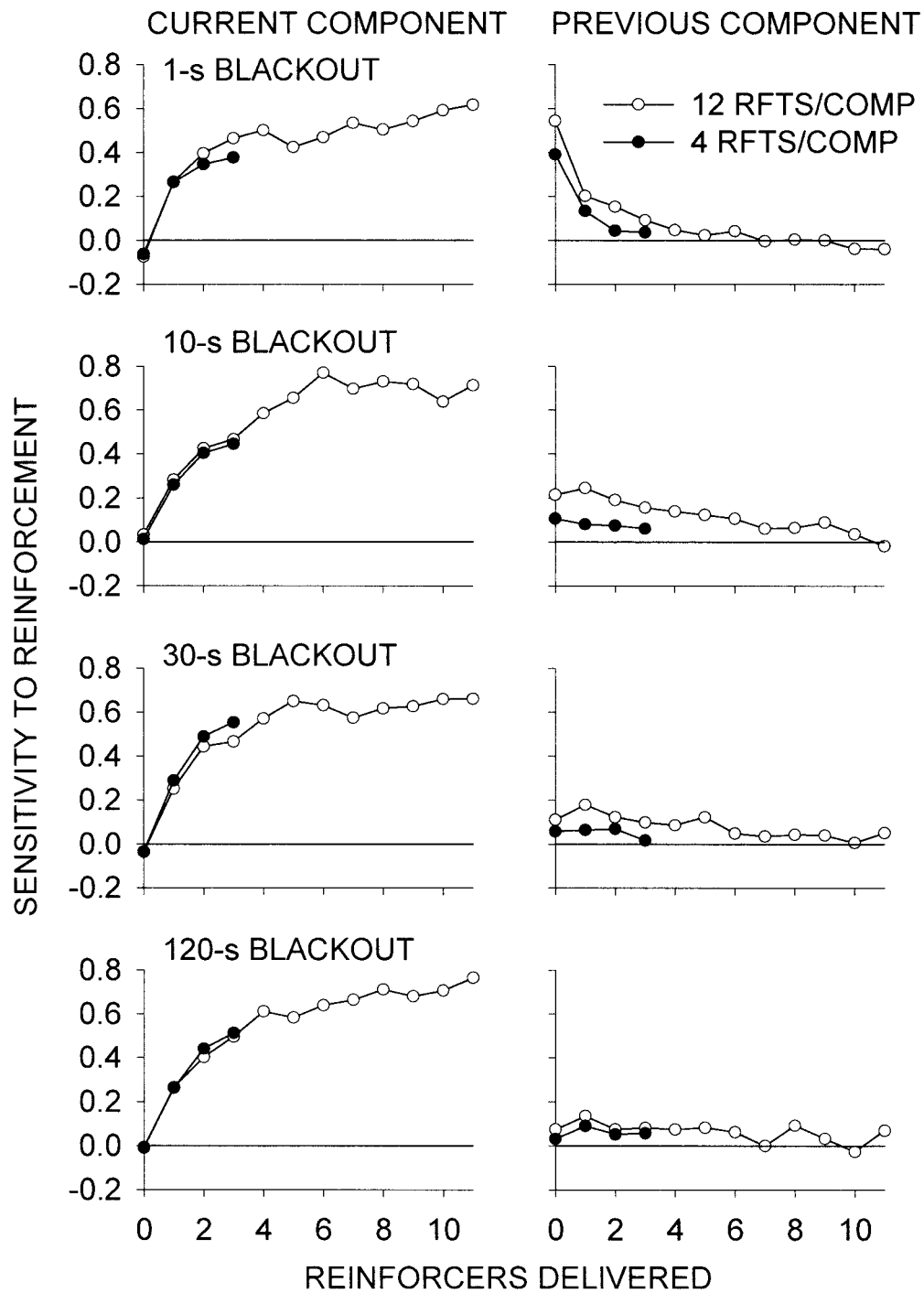
Fig. 1. Sensitivity to reinforcement values at each intercomponent blackout duration obtained using Equation 1 for performance between reinforcer deliveries as a function of both the current (left panels) arranged component reinforcer ratio and the previous (right panels) arranged component reinforcer ratio. Data are the averages of all 6 birds at four and 12 reinforcers per component.
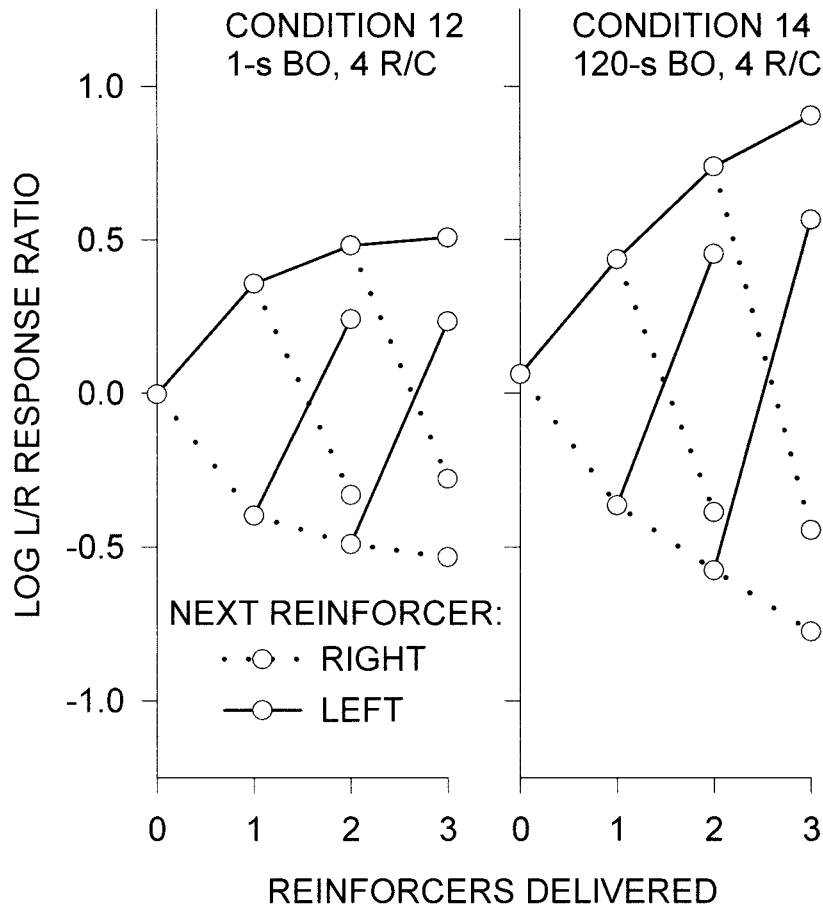
Fig. 2. Effects of consistent sequences of left-key or right-key reinforcers, and of these sequences followed by a single reinforcer on the other alternative (disconfirmation) for the shortest (left panel) and the longest (right panel) intercomponent blackouts with four reinforcers per component.

component: In the individual data, carryover sensitivities remained significantly greater than zero (sign test; $p < .05$) before the first to the fourth reinforcer for both four and 12 reinforcers per component, and became nonsignificant following the fourth reinforcer for 12 reinforcers per component.

Figures 2 (four reinforcers per component) and 3 (12 reinforcers per component) show the effects on response ratio of some selected sequences of left- and right-key reinforcers. The sequences are those in which a series of left-key (or right-key) reinforcers were delivered and those in which a series of left-key (or right-key) reinforcers were followed by a single right-key (or left-key) reinforcer. Davison and Baum (2000) called the latter "disconfirmations." This analysis re-

lates only indirectly to the components because these sequences could, and often did, occur in several of the components. Figure 2 shows response ratios with the shortest and longest blackouts with four reinforcers per component. The difference in vertical spread of the points in the two graphs shows that successive same-key reinforcers ("confirmations") shifted response ratio more strongly following the longer intercomponent blackout. Disconfirmations always moved performance strongly toward the source of that reinforcer, and these moves were larger for the longer intercomponent blackout. Figure 3 shows much the same effects, but the clarity is spoiled to some extent by increasing variance, resulting from a decreasing number of sequences, as the number of consecutive re-
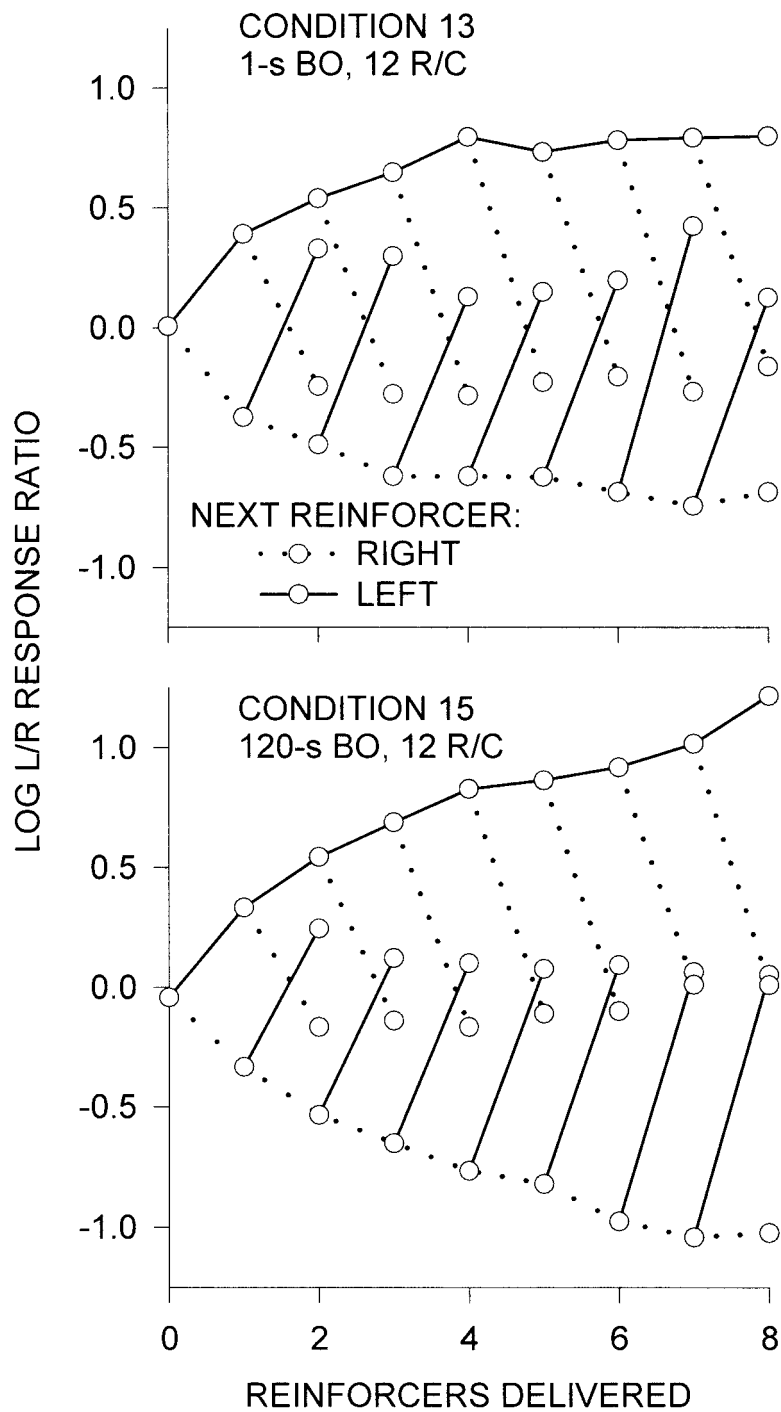
Fig. 3. Effects of consistent sequences of left-key or right-key reinforcers, and of these sequences followed by a single reinforcer on the other alternative (disconfirmation) for the shortest (upper panel) and the longest (lower panel) intercomponent blackouts with 12 reinforcers per component.
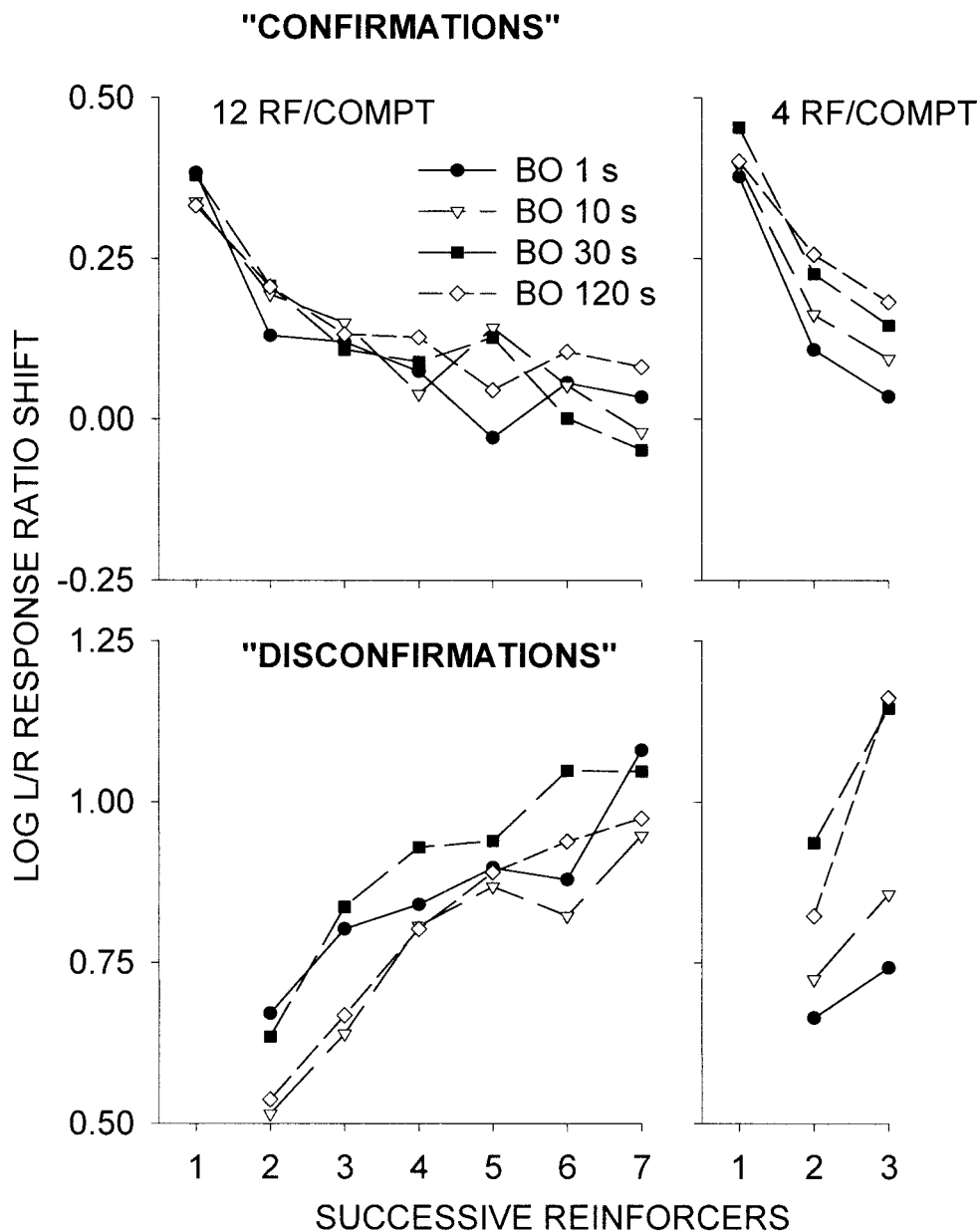
Fig. 4. Top: mean shift in log response ratio across successive same-alternative reinforcers in a component for each intercomponent blackout duration. Bottom: mean shift in log response ratio caused by disconfirmations after sequences of successive same-alternative reinforcers for each intercomponent blackout duration.

inforcers increased. Overall, however, any consistent sequence of reinforcers had more effect with the 120-s blackout. With the 1-s blackout, response ratio ceased to change after about four reinforcers in a component. Again, disconfirmations always changed preference strongly toward the source, although

the size of the shift was about the same for the two blackout durations.

Do strings of reinforcers on the same alternative (i.e., confirmations) have greater effects with longer intercomponent blackouts? The top two graphs in Figure 4 show the shift in response ratio produced by each successive

reinforcer in a series of confirmations. These shifts were averaged across left and right sequences of confirmations and plotted as a function of the number of reinforcers in the sequence for each blackout duration. As would be expected from the negative acceleration of the curves in Figures 2 and 3, the shift produced by each successive confirmation decreased with increasing number of reinforcers for both four and 12 reinforcers per component. On the whole, the rate of this decrease was about the same for four and 12 reinforcers per component. With four reinforcers per component, blackout duration showed a systematic relation to preference change: The shorter the blackout, the faster preference shift declined with number of confirmations. No such relation was evident with 12 reinforcers per component.

The lower panels in Figure 4 show the effects of disconfirmations following different numbers of confirmations. The *x* axis shows the number of confirmations preceding the disconfirming reinforcer. For both four and 12 reinforcers per component, the effect of a disconfirmation increased. Except for the 1-s blackout, the effects tended to be larger and to increase faster with four reinforcers per component. As was true for the confirmations, blackout duration had no discernible effect with 12 reinforcers per component but showed a systematic effect with four reinforcers per component: The longer the blackout, the greater the effect of the disconfirmation.

Did response ratios move towards indifference between reinforcers within components? Figures 5 (12 reinforcers per component) and 6 (four reinforcers per component) show response ratios in 5-s bins following three left-key or three right-key confirming reinforcers. Response ratios following three confirmations were used to ensure a relatively consistent starting point—had we begun following just one reinforcer, the starting point would have been different depending on whether this reinforcer had been a confirmation or a disconfirmation. As we consider longer and longer times since reinforcement, fewer and fewer occasions occurred on which those times were attained, so the variance in response ratio increased as time since reinforcement increased. In the first 5-s bin following three confirmations,
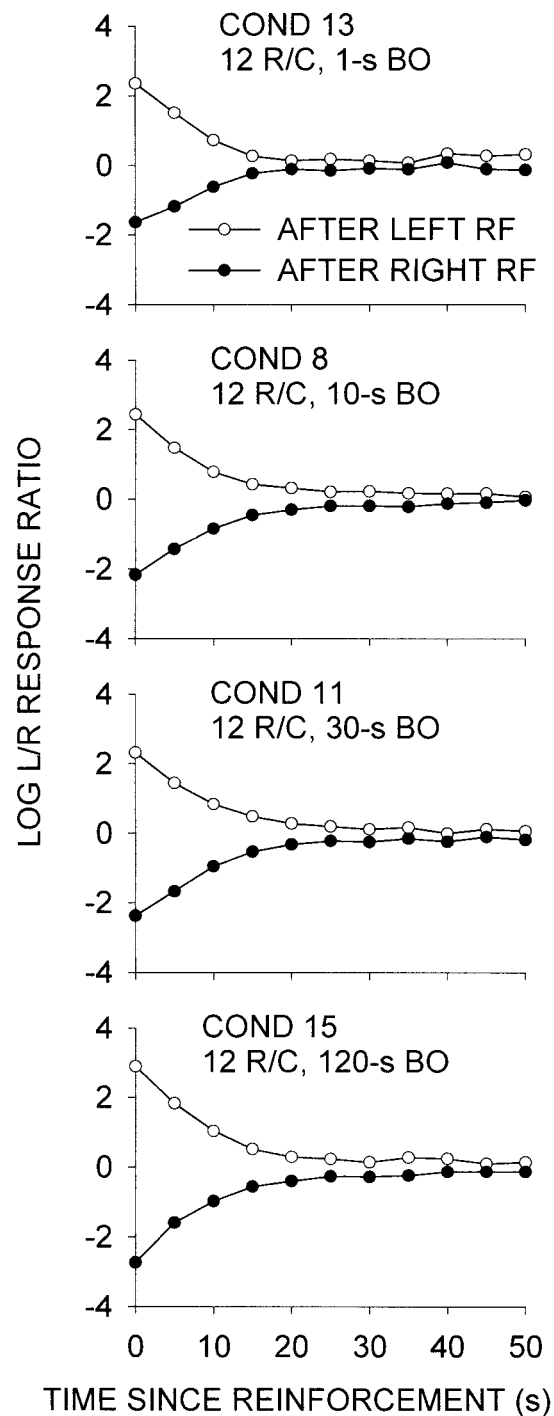

Fig. 5. Preference as a function of time since three reinforcers in a row on the left or right key with 12 reinforcers per component. Because measures were truncated by subsequent reinforcers, the number of samples analyzed decreased with time since reinforcement.
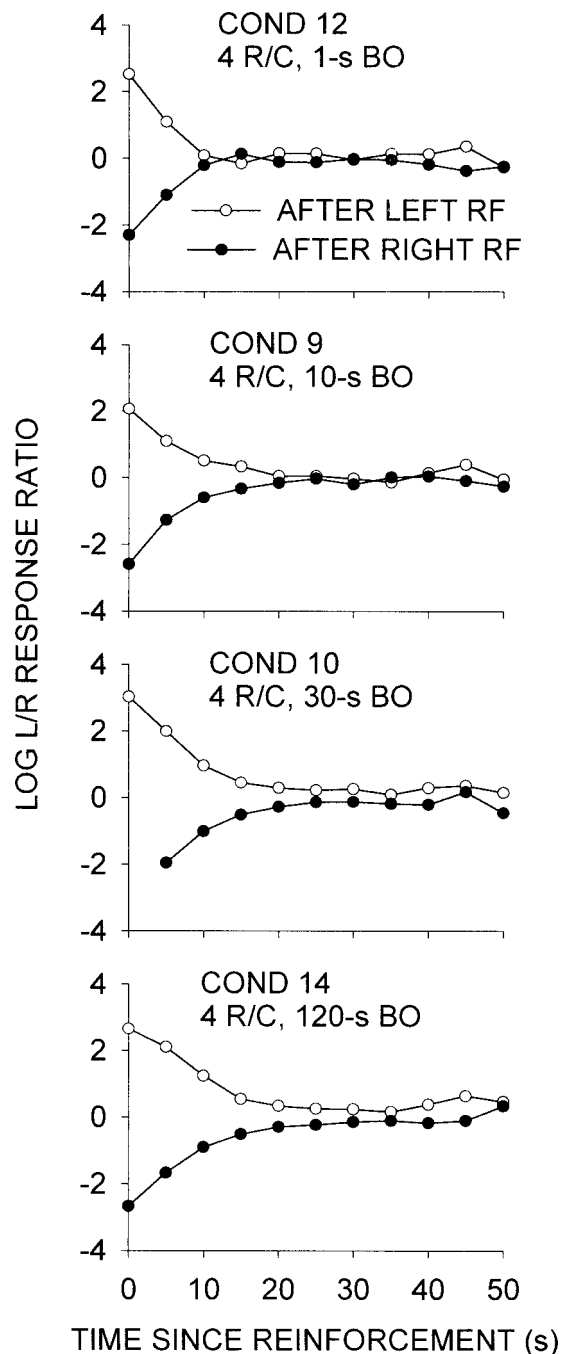
Fig. 6. Preference as a function of time since three reinforcers in a row on the left or right key with four reinforcers per component. Because measures were truncated by subsequent reinforcers, the number of samples analyzed decreased with time since reinforcement. One point for Condition 10 is missing because its response ratio was infinitely negative.

preferences for the reinforced alternative were extreme, often exceeding 100:1. Response ratios then changed progressively toward indifference over the following 50 s. However, small residual effects of previous reinforcers were still evident after 50 s. For the 1-s blackout, the decrease in preference may have been faster with four reinforcers per component than with 12 reinforcers per component. For the other blackout durations, the patterns of decrease were almost identical with four or 12 reinforcers per component.

DISCUSSION

The present results replicated those reported by Davison and Baum (2000) and Landon and Davison (2001) in a number of ways. First, the effects of previous-component reinforcer ratio carried over to response ratios in the next component (Figure 1), and this carryover between components decreased with successive reinforcers in a component (Figure 1). Second, reinforcer-by-reinforcer analyses showed that successive reinforcers delivered for an alternative rapidly moved responding toward that alternative, but generally with decreasing marginal effect as the number of confirmations (successive reinforcers at the same alternative) increased (Figures 2 and 3). Third, a disconfirmation (a reinforcer gained on an alternative that was different from previous reinforcers) shifted response ratio toward the alternative on which the disconfirmation occurred, and this shift increased with increasing number of preceding confirmations (Figures 2, 3, and 4). All of these results are in accord with those reported by Davison and Baum (2000).

The main purpose of the present experiment was to investigate the effect of varying the duration of the intercomponent blackouts. Lengthening the blackout decreased the amount of carryover of choice from one component to the next (Figure 1, right panels), at least as measured prior to the delivery of the first reinforcer in the next component. This finding agrees with the predictions of the Davison-Baum (2000) model. Equally, as time passed between reinforcers, choice showed the predicted decrease in preference (Figures 5 and 6), from high levels immediately after a reinforcer to levels close to (but not at) indifference 30 s to 50 s after the reinforcer. This decrease is consistent with the

effects of blackout duration: Ending the blackout after just 1 s allowed strong carry-over, whereas longer durations reduced carryover close to (but not all the way, even after 120 s) indifference (i.e., zero sensitivity; Figure 1). The large preference following three same-alternative reinforcers (Figures 5 and 6) probably reflected a high probability of revisiting the same alternative immediately after a reinforcer. We may conclude tentatively that choice changed similarly during a period of nonreinforcement and during the intercomponent blackout, although the size of the changes might have differed, because, in Figures 5 and 6, measurement always followed three confirmations in a row, whereas in Figure 1, choice was averaged across sequences of reinforcers that contained, or even ended with, a reinforcer from the nonpreferred alternative.

Preference in the beginning of a component grew about equally fast, regardless of blackout duration; following the first reinforcer, sensitivity jumped to about 0.3 (Figure 1), and preference shifted toward the first-reinforced alternative by about 0.35 of a log unit (Base 10; Figure 4). The Davison-Baum (2000) model predicts that lengthening the blackout should have increased the effect of the first reinforcer because of increasing loss of reinforcers from the accumulators, and such a loss is required in order to predict that the first few reinforcers in a component have a strong effect on preference, as we found. We return to this problem after discussing the results of Experiment 2.

The movement of choice toward indifference between components occurs during blackout, which is a period of signaled extinction. A similar movement toward indifference between reinforcers occurs during periods of unsignaled extinction (Figures 5 and 6). Both of these results, and our model, appear to be incompatible with research reported by Myerson and Hale (1988). They investigated the transition between concurrent VI VI schedules (providing about a 2:1 reinforcer ratio) and unsignaled extinction. Preference remained unchanged over six to 12 sessions of extinction, a result that Myerson and Hale took to support the kinetic model (Myerson & Miezin, 1980) over melioration (Herrnstein & Vaughan, 1980). Skinner (1950) reported a similar result. Nevin

(1969), however, using discrete-trial concurrent VI VI schedules, found that preference moved toward indifference over 10 sessions of unsignaled extinction. Myerson and Hale suggested that different rules may apply to free-operant and discrete-trial performances and offered the reason that discrete-trial procedures include a period of signaled extinction between trials. Because the present experiment included periods of signaled extinction between components, their suggestion might lead us to expect movement toward indifference between components, as we found. Myerson and Hale's suggestion, however, does not help us to understand the similar preference change between reinforcers within components.

EXPERIMENT 2

In Experiment 1, we investigated decreases in preference during the intercomponent blackout by measuring the residual preference at the start of the next component. Our model assumes that preference decreases during the intercomponent blackout in the same way as it does between reinforcers within components, and the residual preferences found in Experiment 1 supported this assumption. Our aim in Experiment 2 was to measure the change in preference between components in a continuous fashion by allowing responding to continue between components. We replaced the intercomponent blackout with a 60-s period of unsignaled extinction, during which the keylights remained on but no reinforcers were available. The next component started at the end of this extinction period, and its start also was unsignaled. Our model implies that the preference decreases should be the same as those following an intercomponent blackout.

METHOD

Subjects, Apparatus, and Procedure

We used the same subjects and apparatus as in Experiment 1. The procedure for Experiment 2 differed from that used in Experiment 1 in three ways. First, no COD was in effect during Experiment 2. Because of this change, we arranged two conditions (24 and 25) with 60-s intercomponent blackouts for comparison purposes. Second, in Conditions 22 and 23, the intercomponent blackout was

removed and replaced by a 60-s period of un-signaled extinction that ended, with no fur-ther signal, with the start of the next, ran-domly selected component. We separately coded and collected all responses emitted during the extinction period. Third, the over-all arranged reinforcer rate in Experiment 2 was 2.22 per minute. In each condition, ei-ther four or 10 reinforcers per component were arranged, with 14 or seven components per session, respectively. The sequence of ex-perimental conditions is shown in Table 1. Conditions 16 to 21, which arranged no COD, are not reported here.

RESULTS

The changes in method from Experiment 1 to Experiment 2 (e.g., removal of the COD) dictate that we first determine whether the same pattern of results occurred in Experi-ment 2 as in Experiment 1. Figures 7 and 8 show the effects of consistent sequences of left-key or right-key reinforcers (confirma-tions) and the effects of changes in reinforcer location (disconfirmations) after such se-quences for blackout (Figure 7) and for ex-tinction (Figure 8). The closest across-exper-iment comparison is between Figure 7 and the conditions in Experiment 1 with 120-s blackouts. Comparison of the graphs in Fig-ure 7 with those in Figures 2 (right panel) and 3 (bottom panel) reveals that although response ratios with a COD were generally more extreme than without a COD, the two experiments produced the same *pattern* of re-sults. Comparison of Figure 7 with Figure 8 reveals that replacing blackout with unsigna-led extinction between components further moderated the response ratios without affect-ing the pattern of results.

To see how preference changed during ex-tinction, we counted the number of respons-es to the two alternatives in 5-s bins during the extinction period, separately for each of the prior seven components. Figures 9 and 10 show choice during extinction with four re-inforcers per component (Condition 22) and with 10 reinforcers per component (Condi-tion 23) for each pigeon. The pattern of change during extinction was similar for both conditions: Response ratios moved towards indifference with increasing time in extinc-tion, starting with a preference that reflected the reinforcer ratio in the prior component.

The asymmetry of preferences for left and right showed some overall negative (right-key) bias for Pigeons 92 and 94 but some pos-itive (left-key) bias for Pigeons 93, 95, and 96. Response ratio ceased to change after about 30 s for four reinforcers per component, and possibly a bit later for 10 reinforcers per com-ponent, although this pattern varied across subjects. However, even after 60 s, differences in preference remained as a function of the reinforcer ratio in the component preceding extinction, and preference stood further from indifference after 10 reinforcers in a component than it did after four reinforcers.

Figures 11 and 12 show choice in 5-s bins, as in Figures 9 and 10, but with the bins ex-tended into the next component until 25 s had elapsed or until a reinforcer occurred, and with the raw data (response numbers) summed across all 6 pigeons. They also show choice in 5-s bins for the first 25 s following blackout. Comparison of symmetrical com-ponents (27:1 with 1:27, etc.) reveals an over-all bias in favor of the right key, as could be seen in Figures 7 and 8. An analysis of indi-vidual-subject data showed that this bias re-sulted from a large bias in Bird 95's prefer-ence, with lesser biases contributed by Birds 91 and 94. Choice following blackout gener-ally fell close to choice following unsignaled extinction. In support of this, individual-sub-ject analyses showed that Birds 91 and 95 in the four reinforcers per component condi-tions had significantly higher preferences postblackout than postextinction, whereas Birds 92 and 94 showed significant differenc-es in the other direction (binomial tests). With 10 reinforcers per component, Birds 92, 95, and 96 showed significantly higher pref-erences postextinction, whereas Bird 95 showed a significant effect in the opposite di-rection. Choice was often transiently biased towards the right key in the initial period af-ter blackout, sometimes strongly so with 10 reinforcers per component. This transient enhancement of bias was evident also in Fig-ures 7 and 8 in the difference in degree of negative (right-key) bias between blackout and extinction before the first reinforcer.

For comparison, Figures 11 and 12 include data from Experiment 1. The filled squares show choice in the first 5 s following black-outs of 1-, 10-, and 30-s duration. Ignoring the differences in method (particularly the COD)
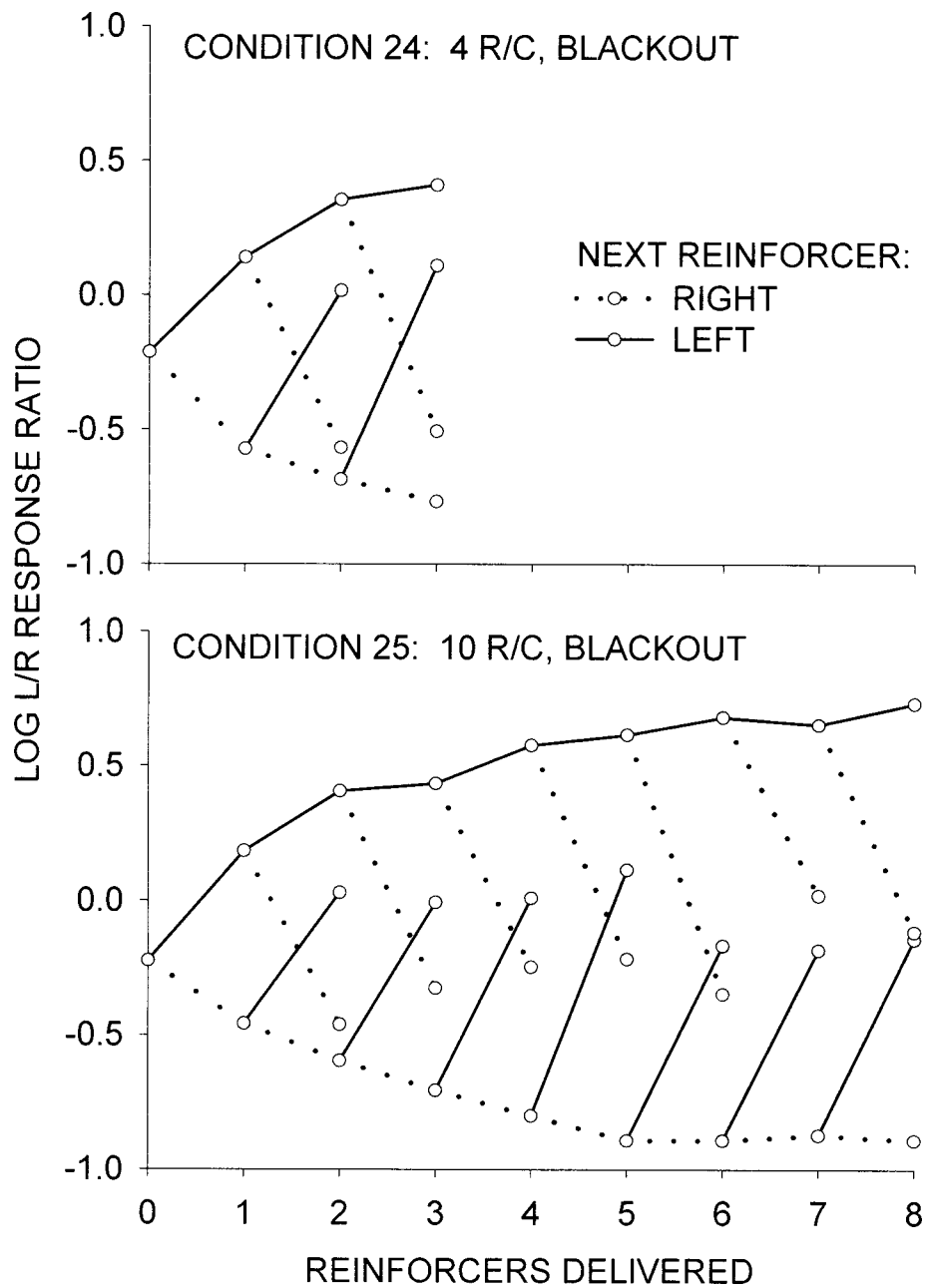
Fig. 7. Effects of consistent sequences of left-key or right-key reinforcers, and of these sequences followed by a single reinforcer on the other alternative (disconfirmation) with four (top graph) and 10 (bottom graph) reinforcers per component and 60-s blackouts between components.

one might connect the squares with the first filled circle to estimate the change in choice that occurred following blackouts of various durations or at various times during a blackout of 60 s. For the components with unequal reinforcement of the two alternatives, choice following blackout (squares) invariably fell closer to indifference than did choice during extinction at the comparable times (open circles).

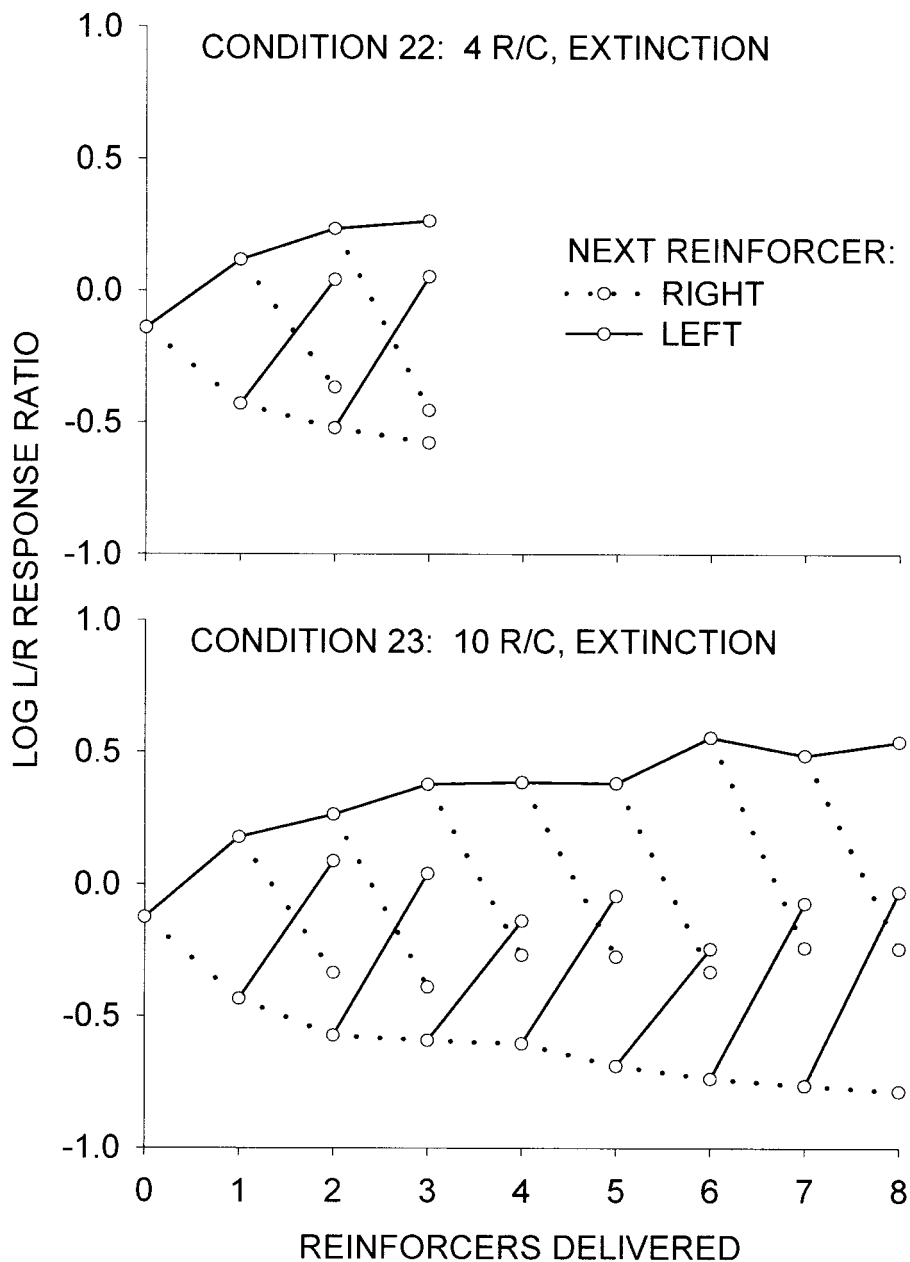Figures 13 and 14 show response rate during and after unsignaled extinction and after

Fig. 8.   Effects of consistent sequences of left-key or right-key reinforcers, and of these sequences followed by a single reinforcer on the other alternative (disconfirmation) with four (top graph) and 10 (bottom graph) reinforcers per component and 60-s periods of unsignaled extinction between components.

the 60-s blackout. Response rate fell somewhat between 5 and 15 s after the start of extinction, and then remained relatively constant before falling again after the next component began. The fixed duration of the blackouts apparently allowed temporal dis-crimination. During the first 5 s of the new component, response rate was systematically lower following blackout than following unsignaled extinction. Except for this difference, which represents an initial acceleration following blackout, the fall in response rate
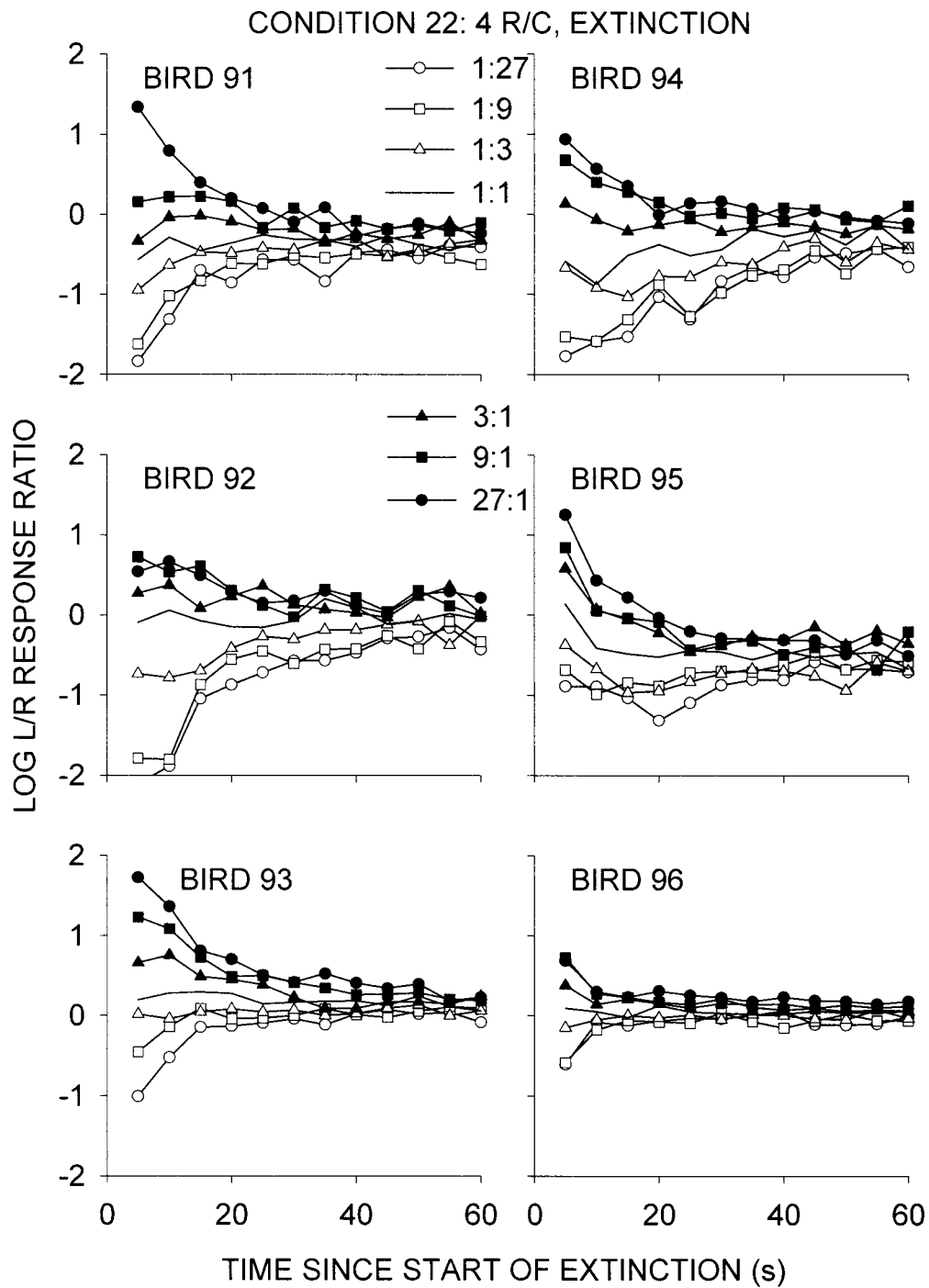
Fig. 9. Log response ratios in 5-s bins during the 60-s unsignaled extinction periods with four reinforcers per component for each bird. Data are shown separately for the 60 s of extinction following each of the seven different component reinforcer ratios. One data point for Bird 92 fell off the graph at a value of −2.11.
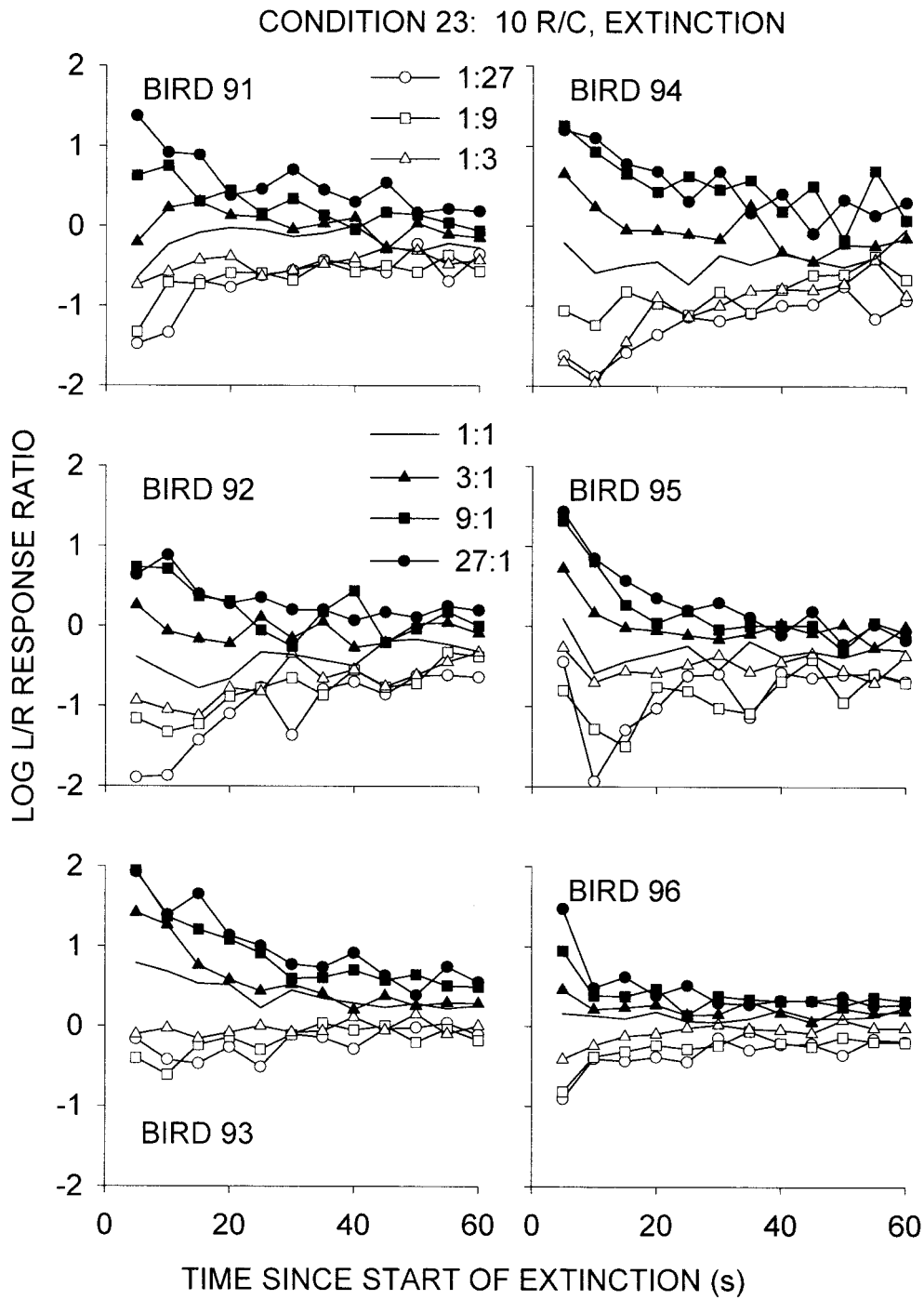
Fig. 10. Log response ratios in 5-s bins during the 60-s unsignaled extinction periods with 10 reinforcers per component for each bird. Data are shown separately for the 60 s of extinction following each of the seven different component reinforcer ratios.
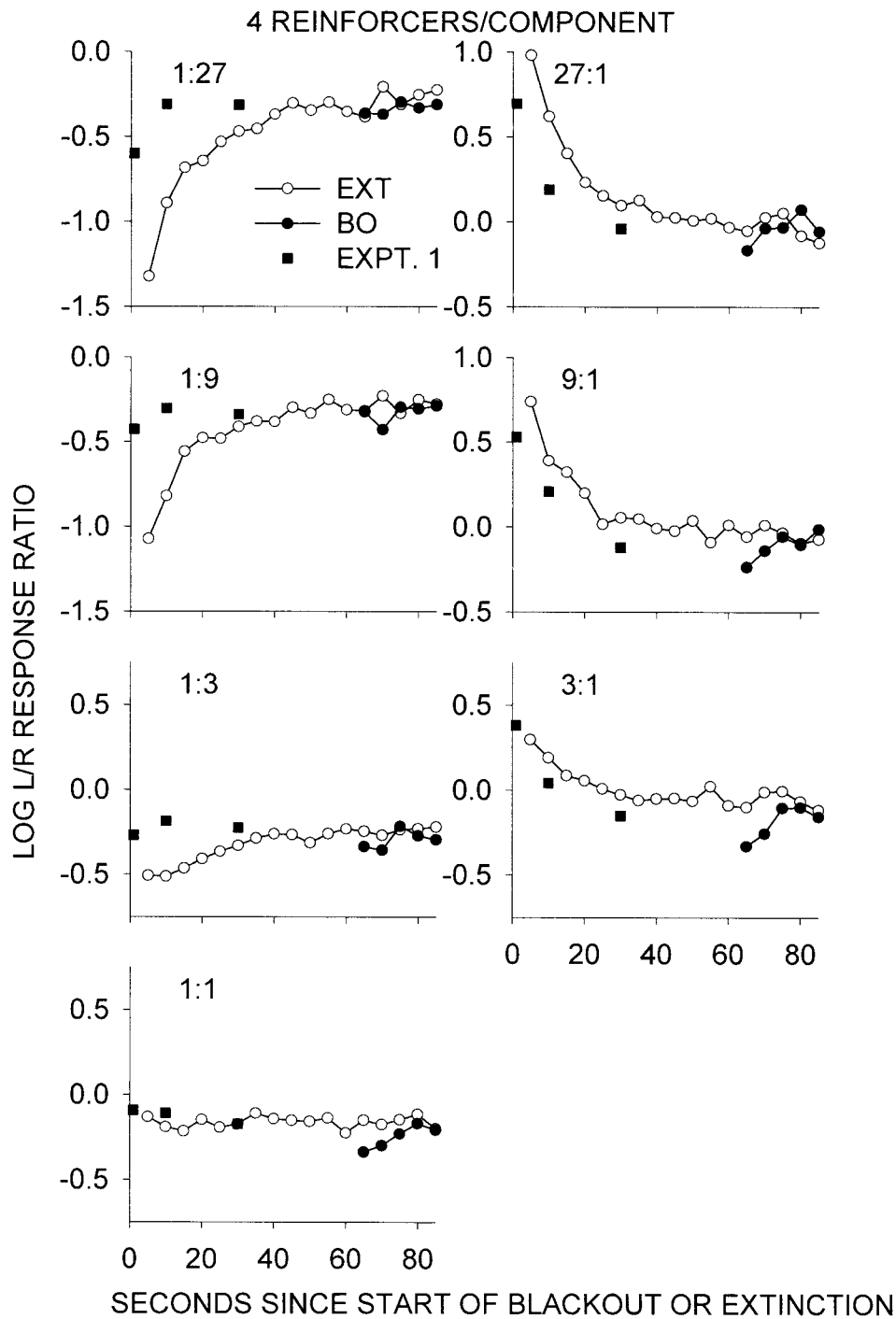
4 REINFORCERS/COMPONENT

Fig. 11. Group log response ratio in 5-s bins during the 60-s unsignaled extinction periods and 25 s into the next component or until a reinforcer was obtained in the next component, for both unsignaled extinction (open circles) and blackout (filled circles) conditions with four reinforcers per component. Data are shown separately following each of the seven different component reinforcer ratios. Filled squares show log response ratio in the first 5 s following blackouts of 1, 10, and 30 s from Experiment 1. Note the different scales on the y axes.
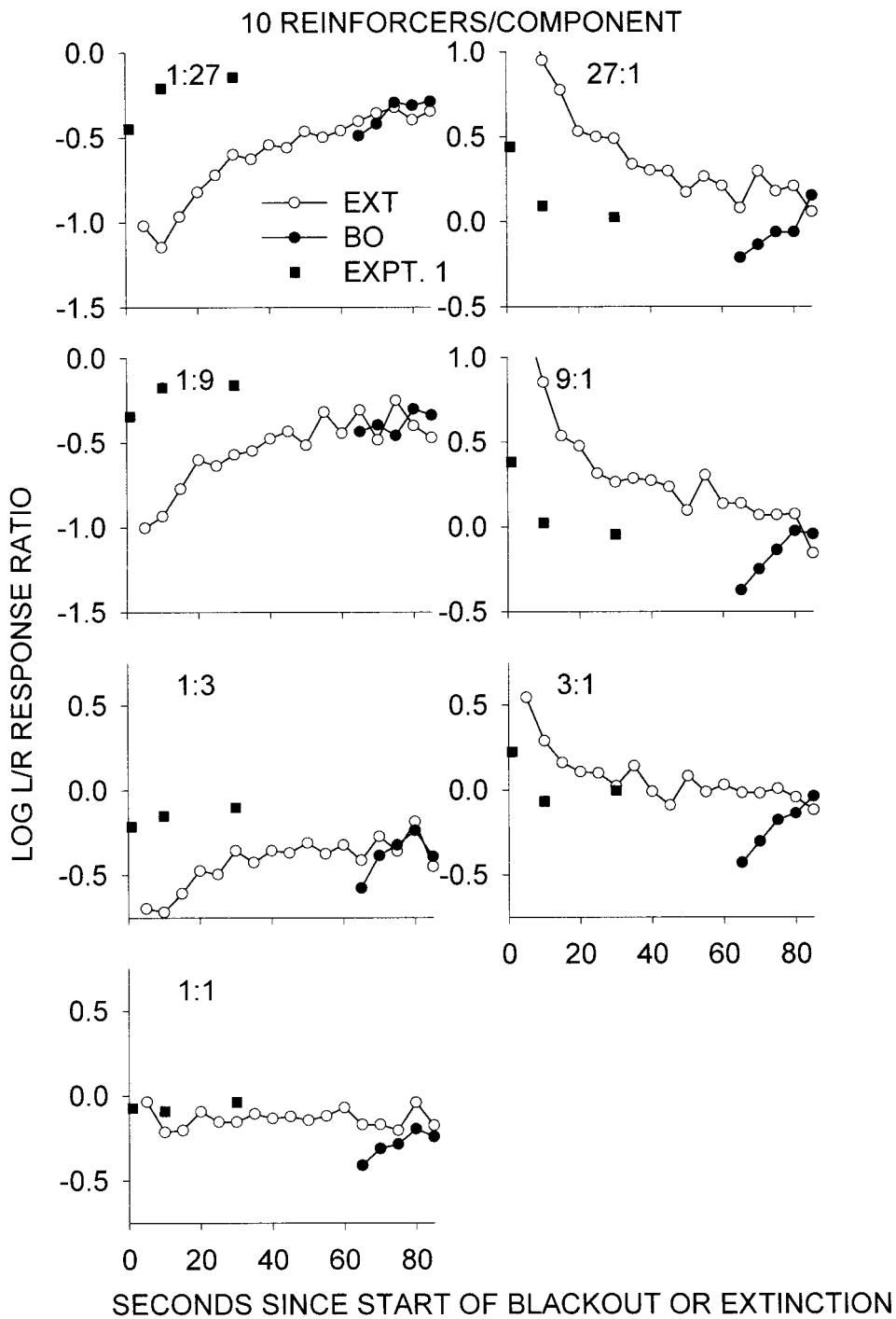
Fig. 12. Group log response ratio in 5-s bins during the 60-s unsignaled extinction periods and 25 s into the next component or until a reinforcer was obtained in the next component, for both unsignaled extinction (open circles) and blackout (filled circles) conditions with 10 reinforcers per component. Data are shown separately following each of the seven different component reinforcer ratios. Filled squares show log response ratio in the first 5 s following blackouts of 1, 10, and 30 s from Experiment 1 (12 reinforcers per component). Note the different scales on the y axes.

Fig. 13. Group response rate in 5-s bins during the 60-s unsignaled extinction periods and 25 s into the next component or until a reinforcer was obtained in the next component, for both unsignaled extinction (open symbols) and blackout (filled symbols) conditions with four reinforcers per component. Data are shown separately following each of the seven different component reinforcer ratios.
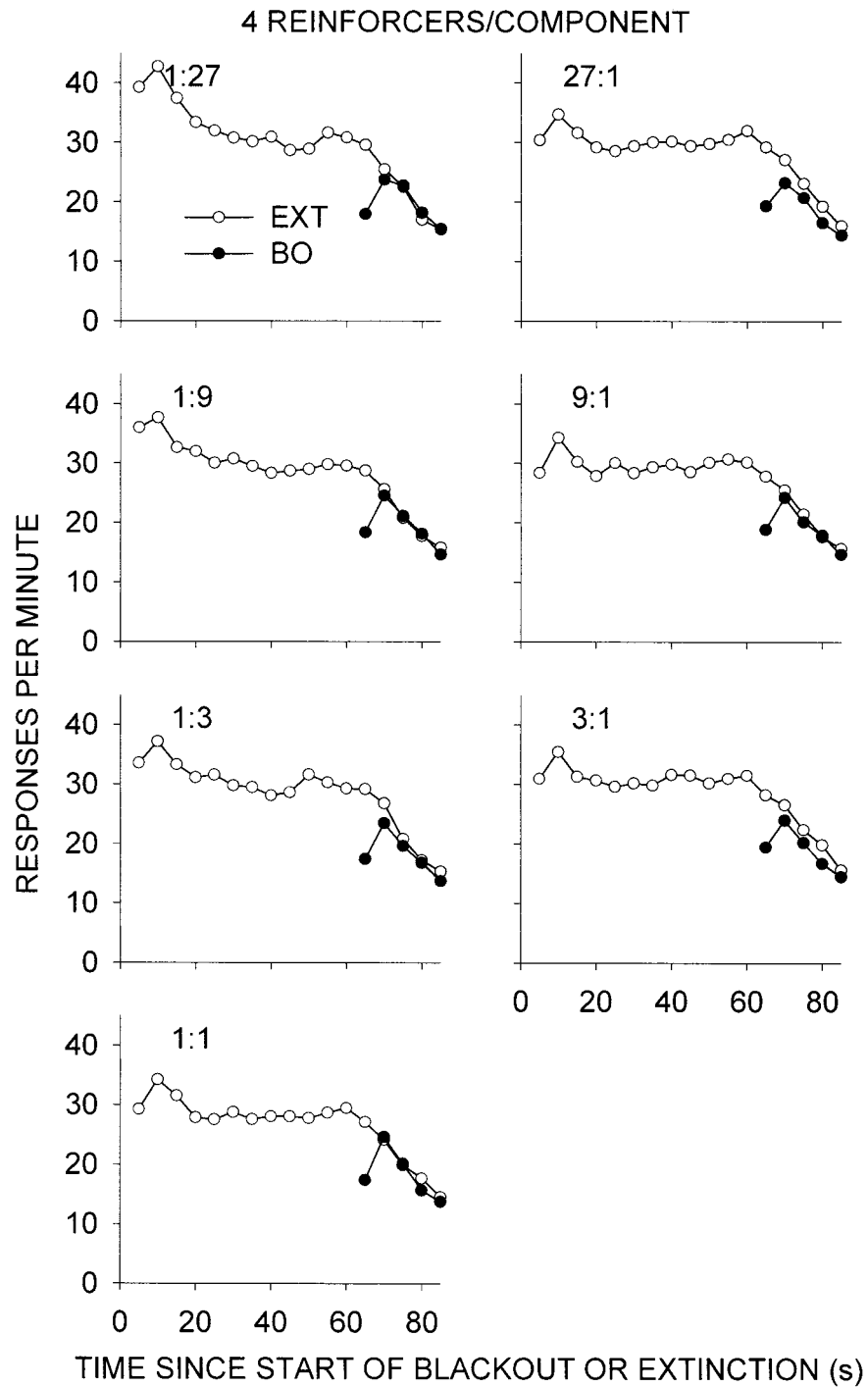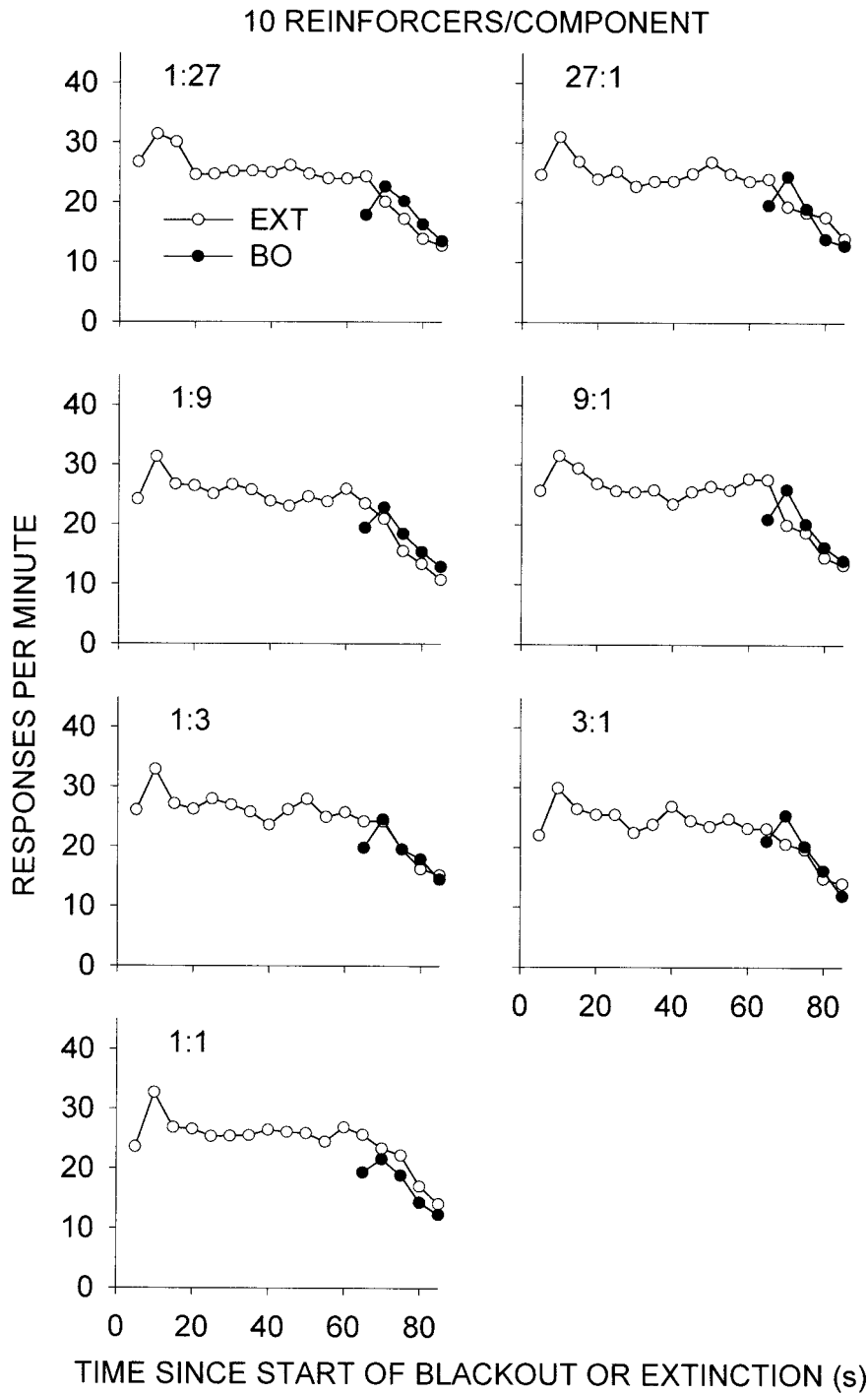
Fig. 14. Group response rate in 5-s bins during the 60-s unsignaled extinction periods and 25 s into the next component or until a reinforcer was obtained in the next component, for both unsignaled extinction (open symbols) and blackout (filled symbols) conditions with 10 reinforcers per component. Data are shown separately following each of the seven different component reinforcer ratios.

after blackout was almost identical to that following unsignaled extinction. Comparison of Figures 13 and 14 reveals that response rate was systematically higher during extinction with four reinforcers per component than with 10 reinforcers per component.

Figure 15 presents a comparison of choice during extinction with choice between reinforcers. To make a direct comparison, we needed a consistent starting point from which to assess the effects of nonreinforcement. Analysis as a function of previous component, as in Figures 9 to 12, although appropriate for extinction effects on their own, would not allow a comparison with interreinforcer effects because the different components ended in various sequences of reinforcers, and averaging across these would fail to reflect the reinforcer-by-reinforcer shifts in choice that occur within components (Figure 4). From earlier research, we knew that choice within components depends almost entirely on the previous three or four reinforcers (Davison & Baum, 2000; see also Figure 15). Thus, we selected for analysis the eight possible sequences of three reinforcers that occurred either before extinction or within components, and analyzed the response ratios following those sequences. Figure 15 shows the results.

As we found before, response ratios were most strongly affected by the source (left key or right key) of the last reinforcer; choice favored the left following all sequences ending in a left reinforcer and favored the right following all sequences ending in a right reinforcer. Reinforcer source prior to the last reinforcer, however, also affected the response ratio. For example, sequences ending in LL (two left reinforcers in a row) were followed by stronger preference than were those ending in RL (left reinforcer preceded by a right reinforcer), and similarly for sequences ending in RR in comparison with those ending in LR. The third reinforcer back also affected choice. For example, LLL and RRR sequences were always followed by stronger preferences than RLL and LRR.

Choice moved toward indifference with increasing duration of nonreinforcement following all sequences but failed to fall all the way to indifference after 60 s, particularly for the homogeneous sequences (LLL and RRR). In support of this conclusion, analyses

of individual-subject differences in preference between mirror-image sequences (e.g., LLR and RRL) were carried out. If these differences were significantly greater than zero, preference failed to return to indifference. The results showed that, both during the extinction period and during the components, the LLL-RRR preference difference was significantly greater than zero (binomial tests; $p < .05$) in every condition. The RLL-LRR preference differences were significantly greater than zero in all four in-component analyses and in Condition 22 of the extinction analyses. The LRL-RLR difference was significantly greater than zero for four of the six analyses, and the RRL-LLR differences were significant, but in a negative direction, only in Condition 23 during the extinction period. The curves following left and right reinforcers all appeared similar in shape, so much so that they appeared to differ simply by constant amounts of bias; that is, all sequences following a left or a right reinforcer could be superimposed by moving them vertically on the graphs. As would be expected from Figures 7 and 8, choice diverged more from indifference with 10 reinforcers per component than with four reinforcers per component. Finally, in Conditions 22 and 23, for which the comparison could be made, the decay of preference followed similar courses during intercomponent extinction and within-component interreinforcer periods, as might be expected (cf. top and middle graphs in Figure 15). More important, however, these results also resembled those during the interreinforcer periods when the intercomponent event was blackout (Conditions 24 and 25).

GENERAL DISCUSSION

First, the results of this study replicated and extended those of Davison and Baum (2000). We found the same diminishing effects of repeated reinforcers at an alternative and the same major effects of disconfirmations of those sequences (Figures 2, 3, 4, 7, and 8) on preference. We again found carryover of choice from one component to the next with short blackouts between components, but found here that carryover from the previous component decreased with longer blackouts (Figure 1). Experiment 2 showed further that the carryover falls in a similar fashion during
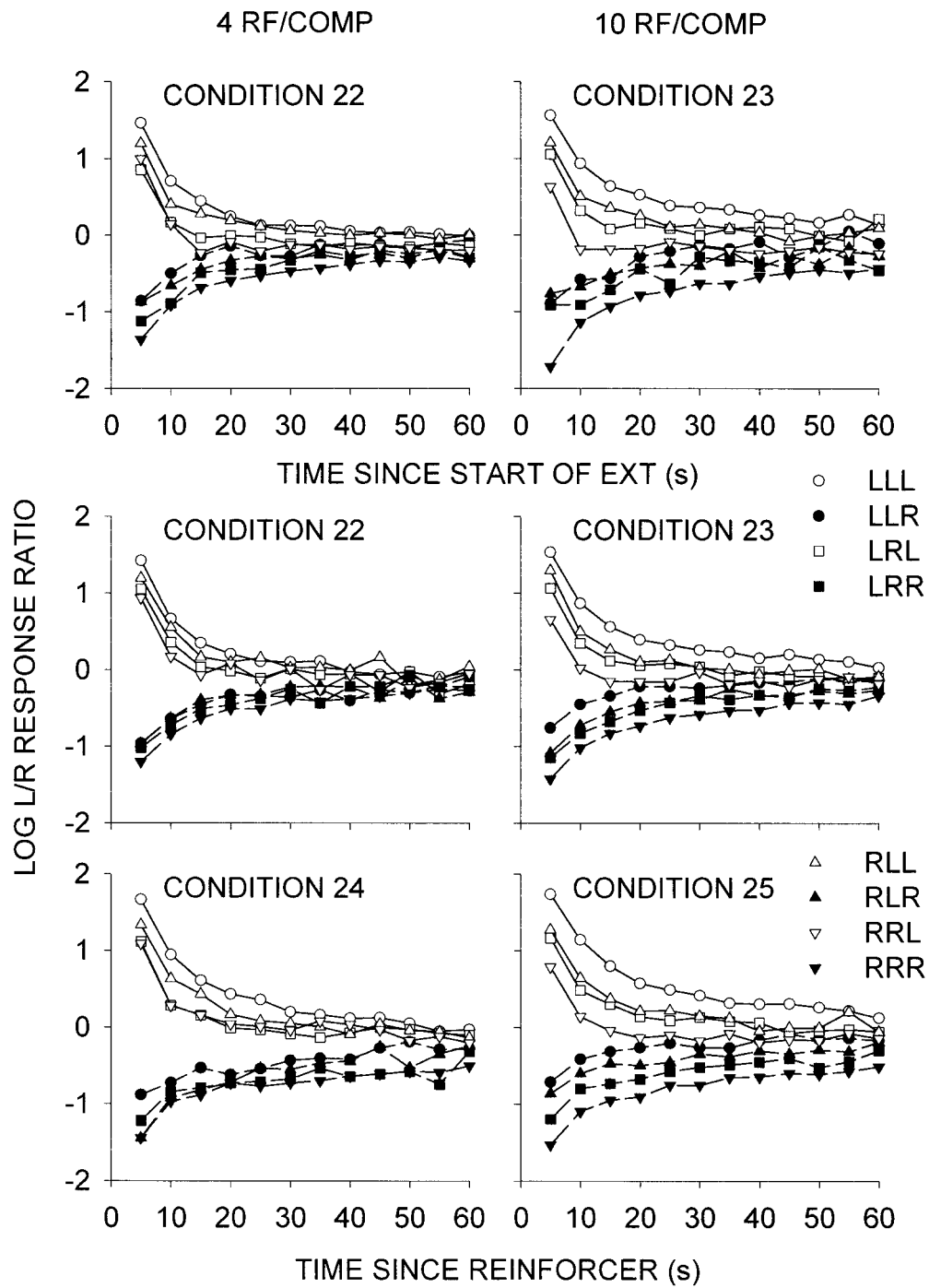
Fig. 15. Group log response ratio in 5-s bins after all possible sequences of three reinforcers. The top graphs show performance during unsignaled extinction in Conditions 22 and 23. The middle graphs show choice following the same sequences of three reinforcers during the interval before the next reinforcer with unsignaled extinction between components. The bottom graphs show choice following the same sequences of three reinforcers during the interval before the next reinforcer with blackout between components.

blackout between components, during unsignaled extinction between components (Figures 11 and 12), and from reinforcer to reinforcer within components (Figure 15). The results thus support an important part of the originally suggested model, which assumed that during periods of nonreinforcement (be they interreinforcer periods or periods of blackout), the contents of the two accumulators progressively mix and thus become more equal. The mixing appeared to be remarkably slow during extinction, however, taking a minute or more (Figures 11, 12, and 15).

Although the decay of preference during periods of nonreinforcement supports the model, a crucial question remains unanswered. Neither the present results nor the earlier ones allowed us to determine whether this regression of preference is toward indifference or toward some global average of the reinforcer ratios. Because both experiments equated reinforcement at the two alternatives overall, a global average would predict eventual indifference. Indeed, Landon and Davison (2001) reported results suggesting that the regression may be toward an average, rather than toward zero, and we have further, as yet unpublished, data that support their suggestion. If the regression were toward the mean, then the model would also require a long-term accumulator. This idea gains support from Figure 15, which shows that choice remained divergent following various sequences of reinforcer source, even up to a minute since reinforcement with 10 reinforcers per component. Homogeneous sequences (LLL and RRR), in particular, appeared to produce long-lasting increments in preference, suggesting long-term effects of repeated reinforcers from the same alternative. A short-term accumulator that adequately describes the pulses in preference after reinforcers cannot, at the same time, describe a longer term sequences-of-reinforcers effect, nor is it compatible with a simple notion of the "strengthening" of behavior by reinforcement. A longer term accumulator can do both.

Figures 5 and 6 show that immediately following three same-alternative reinforcers, choice rose briefly to extreme levels, often exceeding 100:1. These pulses in preference were unexpected because they have never previously been reported in concurrent VI VI performance. They occurred in both experiments but had smaller amplitude in Experiment 2 (Figure 15, lower graphs), presumably because Experiment 1 included a COD. They reflect a positive recency effect, a tendency to respond at the just-reinforced alternative, particularly when a COD discouraged switching. Postreinforcer preference decayed rapidly at first, reaching moderate levels in about 10 s with a 1-s intercomponent blackout and in about 20 s with a 120-s blackout, but decayed more slowly after that, usually leaving a long-term difference, even after 50 s (Figures 5, 6, and 15).

The pulses and the decay could be interpreted in at least two ways. They might indicate that every reinforcer has a powerful immediate effect that decays according to a continuous function with a relatively long tail. Such a function could produce the global averaging of reinforcer ratios mentioned above. Alternatively, as we suggested earlier, each reinforcer might have two effects, captured by two accumulators per alternative—one that receives a large short-term increment from each reinforcer, but with rapid loss and rapid mixing with its counterpart for the other alternative, and a second that receives a small increment, but with slow loss and slow mixing. This second accumulator would gradually fill up in an experiment that maintained the same pair of VI schedules session after session, eventually to produce familiar steady-state concurrent VI VI performance. This second accumulator would also explain the difference between Myerson and Hale's (1988) results and ours: In their experiment, the long-term accumulators filled during sustained exposure to a 2:1 reinforcer ratio, and, because of slow loss and mixing, maintained preference for a considerable time during extinction. Indeed, this long-term accumulator might maintain appropriate preference across the usual 23-hr session-to-session gap in standard procedures. Supporting this line of theorizing, Hunter (1979) reported that following a transition from one long-maintained reinforcer ratio to another, choice regressed towards the previous condition's response ratio at the start of each session for as many as 11 sessions.

Figures 11 and 12, which allow a comparison, suggest that preference might fall faster during blackout than during unsignaled extinction. Because the presence of a COD in Experiment 1 resulted in stronger preferenc-

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es (Figures 2, 3, and 7), the squares shown in Figures 11 and 12, if anything, underestimate the reduction in preference produced by blackout. Assuming that comparison across the two experiments is valid despite differences in method, we might conclude that the blackout acts to signal an impending change in reinforcer ratio, a change more frequently than not to a component with a reinforcer ratio in the opposite direction. We might expect, considering the many demonstrations of ''directed forgetting,'' that the blackout would lead to rapid loss of control by the previous reinforcer ratio—or that, at least, loss of control would be faster with a blackout than with unsignaled extinction, as Figures 11 and 12 suggest.

Davison and Baum (2000) suggested that the present model should be applicable to performance in standard concurrent VI VI schedules. We are investigating this in ongoing experiments. Other researchers have proposed models that, like ours, rely on relatively local effects, some models even considering processes response by response (e.g., Hinson & Staddon, 1983; Shimp, 1969). As it stands, however, the present model relies on local effects and may make predictions about local behavior, but makes no predictions response by response, predicting, for example, at which alternative the next response will occur. Response ratios, by their nature, have to be measured over time periods, even if, as we have shown, the time periods may be short. Thus, we can predict relative responding to the alternatives over short periods, and we can predict how relative responding will change. If we had a model of response generation, of when the next response would occur, the model then could make response-by-response predictions.

Our predictions for steady-state concurrent VI VI performance will derive from the sequence effects shown in Figures 3, 7, and 15. Because steady-state concurrent VI VI contains many different sequences of reinforcer source, some sort of averaging across sequences will be required. For example, even if three or four successive reinforcers from the same alternative produced the strong preferences shown in Figure 3, the response ratio would never stay at that level because disconfirmations have such large effects (Figures 2, 3, 7, and 8). Thus, if the effects of

successive same-alternative reinforcers were as large as those found here, disconfirmations might have even stronger effects in steady-state concurrent VI VI than in the present procedure. Alternatively, both confirmation and disconfirmation in steady-state concurrent performance might have effects smaller than those shown here.

The present results depend on the collection of large amounts of data. Had we analyzed smaller amounts, we probably would have missed the effects that we have reported. Much the same will be true in the analysis of standard concurrent VI VI performance. In our ongoing research, we are analyzing the last 45 of 60 sessions of concurrent VI VI. Research of this nature is tedious, but a leisurely approach appears to be necessary if we are to extract the local details of performance that have eluded us until now.

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