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SHORT-TERM AND LONG-TERM EFFECTS OF REINFORCERS ON CHOICE

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The relation between molar and molecular aspects of time allocation was studied in pigeons on concurrent variable-time variable-time schedules of reinforcement. Fifteen-minute reinforcer-free periods were inserted in the middle of every third session. Generalized molar matching of time ratios to reinforcer ratios was observed during concurrent reinforcement. Contrary to melioration theory, preference was unchanged during the reinforcer-free periods as well as in extinction. In addition to this long-term effect of reinforcement, short-term effects were observed: Reinforcers increased the duration of the stays during which they were delivered but had little consistent effect either on the immediately following stay in the same schedule or on the immediately following stay in the alternative schedule. Thus, an orderly effect of reinforcer delivery on molecular aspects of time allocation was observed, but because of its short-term nature, this effect cannot account for the matching observed at the molar level.

Key words: choice, matching, short-term reinforcer effects, long-term reinforcer effects, concurrent schedules, extinction, stay durations, time allocation, pigeons

The effects of reinforcers on behavior can be described at multiple levels of analysis that differ in terms of where they fall on a molecular–molar dimension. Molar analyses are broadly based, relying on rates of responding and reinforcement measured over relatively long time periods. Molecular analyses are more narrowly time based, and, unlike molar analyses, the times and positioning of individual responses and reinforcers provide the basis for a theoretical account.

Research at both the molar and molecular levels has yielded an impressive body of behavioral description and theory. However, it remains to be determined how, if at all, the behavioral patterns observed at the two levels relate to one another. Molar-level behavior may be dependent upon, and derive from, a fundamental molecular pattern of behavior. Alternatively, the molar pattern of behavior may be fundamental and not the result of a more molecular process. That is, the same molar pattern could exist across subjects even though molecular patterns might differ among them.

The molecular–molar dichotomy in analysis and theory is evident in the study of choice under concurrent schedules of reinforcement. The generalized matching law (Baum, 1974) provides a quantitative description of choice at a molar level: Behavior is allocated to various alternatives in proportion to the reinforcers obtained from those alternatives. Mathematically stated,

$$B_1/B_2 = b(r_1/r_2)^s, \qquad (1)$$

where B denotes the amount of behavior (responses or time) directed at schedule alternatives 1 and 2, r represents the number of reinforcers obtained from those alternatives, and the constants b and s denote bias and sensitivity. Bias reflects a systematic asymmetry, often of unknown origin, between the alternatives. Sensitivity is manifested as the slope, s, of a line that plots the logarithm of the behavior ratio (B_1/B_2) as a function of the logarithm of the reinforcer ratio (r_1/r_2). When $s < 1$, the behavior is called undermatching; when $s > 1$, the behavior is called overmatching.

The generalized matching law successfully accounts for choice behavior in many species under a wide variety of situations (for reviews, see Davison & McCarthy, 1988; de Villiers, 1977). However, the mechanism by which such steady-state behavior is achieved remains to be specified. Two general approaches can be identified. For some, molar matching cannot (or need not) be reduced to a more fundamental molecular pattern (e.g., Nevin, 1979; Rachlin, Green, Kagel, & Battalio, 1976). Nevin (1979) has argued that because molar

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matching is observed in conjunction with different sequential response patterns, molar matching is "not an artifact or by-product of more molecular processes" (p. 305). For others, although the proposed mechanisms differ, molar matching must derive from a more fundamental molecular process (e.g., Herrnstein & Vaughan, 1980; Killeen, 1982; Myerson & Miezin, 1980; Shimp, 1966; Silberberg, Hamilton, Ziriax, & Casey, 1978; Staddon, 1988).

A number of studies seeking evidence of a molecular process underlying molar matching have looked for sequential patterning within stays at a schedule alternative (e.g., Heyman, 1979; Nevin, 1979; Silberberg et al., 1978). These studies have focused on possible changes in the probability of switching to the other schedule as a function of the time or number of responses since the beginning of a stay. For example, Heyman reported that the probability of switching between concurrent variable-interval (VI) schedules is constant and independent of the number of successive pecks since the beginning of a stay, whereas Silberberg et al. observed that the probability of switching first increased and then decreased as a function of time since the beginning of a stay. However, little attention has been paid to the possibility of sequential patterning between stays at the schedule alternatives (but see Real, 1983), and the influence of the delivery of reinforcers on such patterning has not been examined. For example, does a reinforcer delivery in one schedule increase the duration of immediately subsequent stays in that schedule? Does a reinforcer delivery in one schedule decrease the duration of the subsequent stay in the other schedule?

Although a few studies come close to asking such questions, these previous studies focused on the effects of reinforcers on response probability rather than their effects on temporal measures of behavior. The results concerning the effects of a reinforcer on response probability differ: Some researchers (Fantino & Royalty, 1987; Killeen, 1970) have reported that the probability of responding on a given schedule was lower immediately following delivery of a reinforcer on that schedule; others have reported no change in response probability (Fantino & Royalty, 1987; Nevin, 1969) or a higher probability of responding on the same schedule following reinforcer delivery (e.g., Bailey & Mazur, 1990; Mazur & Ratti, 1991; Menlove, 1975). Thus, it appears that reinforcer delivery may increase or decrease the tendency to respond on the other schedule depending upon the specifics of the procedure (Fantino & Royalty, 1987).

Although the fundamental importance of time as a measure of behavior has been emphasized by numerous authors (e.g., Baum & Rachlin, 1969; Hanson & Green, 1986; Premack, 1965), to our knowledge no study has examined the effects of a reinforcer on the duration of immediately subsequent stays at concurrent alternatives. The present experiment investigated the molar and molecular effects of reinforcers on temporal aspects of choice. Three pairs of response-independent concurrent variable-time (VT) schedules were studied, and the effect of a reinforcer on time spent in each component of the concurrent schedule was examined. At the molar level, time allocation when the schedules were in effect was compared with time allocation during interleaved 15-min periods of nonreinforcement. At the molecular level, the durations of stays during which reinforcers were delivered were compared with preceding and following stays in which reinforcers were not delivered. Finally, molar and molecular aspects of choice were examined during prolonged periods of nonreinforcement.

METHOD

Subjects

Three male White Carneau pigeons were maintained at 80% of their free-feeding body weights. Supplemental feedings were provided after each daily session as needed. All birds were experimentally naive and approximately 1-year old at the start of the experiment.

Apparatus

A standard two-key operant conditioning chamber for pigeons (Coulbourn Instruments) measured 31 cm deep, 33 cm high, and 25 cm wide. The changeover key, 2.54 cm in diameter and located 20.5 cm from the floor and 12.5 cm from the right and left walls, was transilluminated with amber light during experimental sessions. The minimum force required of pecks on the changeover key was approximately 0.1 N, and each effective peck was immediately followed by a feedback click produced by the operation of a relay. A signal key, 2.54 cm in diameter and located 24 cm from the floor and 21 cm from the left wall, could

Table 1

Number of reinforcers and time allocation (in seconds).

	VT schedule		Reinforcers[a]		Time[a]		Reinforcer-free time[b]		Conc VT VT time[b]	
Subject	Green	Red	Green	Red	Green	Red	Green	Red	Green	Red
15	240	120	8.1	16.4	1,066	1,512	361	496	741	1,065
	107	320	19.7	5.6	1,878	785	657	254	1,294	517
	160	160	12.7	13.3	1,265	1,355	437	445	862	945
16	107	320	21.8	5.4	2,275	377	786	110	1,524	270
	160	160	12.7	12.7	1,434	1,169	482	393	970	821
	240	120	9.8	18.5	1,045	1,581	338	540	711	1,094
17	160	160	13.2	12.5	1,356	1,268	448	427	933	871
	240	120	9.1	17.8	939	1,690	305	571	648	1,147
	107	320	21.3	5.6	1,888	744	632	260	1,256	532

[a] Mean data from the last 30 sessions.

[b] Mean data from the last 10 sessions that included the reinforcer-free periods.

be transilluminated with either red or green light, corresponding to which VT schedule was in effect. Pecks to the signal key had no effect. A white houselight was mounted 28 cm from the floor and 3.5 cm from the left wall. An opening (5.5 cm by 5.5 cm) was centered 3.5 cm from the floor and allowed access to an illuminated hopper containing mixed pigeon grains. Masking noise and ventilation were provided by an exhaust fan mounted on the rear of the light- and sound-attenuating box enclosing the chamber. Sessions were controlled by an Apple II+® computer (equipped with a Mountain Computer, Inc. hardware clock) located in an adjacent room.

Procedure

After being trained to eat from the food hopper, the birds were placed on a modified autoshaping procedure in which, on a VT 1-min schedule, the changeover key was illuminated amber for 8 s followed by 4 s of access to mixed grains. Pecks to the illuminated key resulted in immediate food delivery and darkening of the key and houselight. All birds received two such sessions of 50 trials each and were pecking consistently by the second session.

The birds were then placed on a response-independent concurrent variable-time variable-time (*conc* VT VT) procedure similar to that used by Findley (1958). Two independent VT schedules operated continuously, and each schedule delivered its respective reinforcers when the VT had timed out and that schedule was selected by the pigeon. The schedule in effect was indicated by the signal key, illuminated either red or green depending on which schedule was selected. Pecks on the amber changeover key had the effect of switching between the two VT schedules and thus changing the color of the signal key. During reinforcer delivery, the houselight and changeover key were darkened, the signal key remained illuminated, and the food hopper was illuminated and raised for 3 s. If a reinforcer set up on the schedule not being sampled at the time, that schedule stopped and resumed only after the schedule was selected and the reinforcer delivered.

A changeover delay (COD) was included to prevent immediate adventitious reinforcement for changing over. The COD was a 1.6-s period following every effective changeover response during which reinforcers could not be delivered and pecks to the changeover key were ineffective. Reinforcers that set up during the COD were delivered immediately after the COD ended.

Three pairs of VT schedules were studied for each bird: *conc* VT 240 s VT 120 s, *conc* VT 160 s VT 160 s, and *conc* VT 107 s VT 320 s. These values were chosen so that approximately equal overall rates of reinforcement would be earned under all three relative rates of reinforcement. Each bird was studied on a different order of conditions, as shown in Table 1. Values for the VT schedules were calculated using an algorithm developed by Fleshler and Hoffman (1962), and a new, random sequence of intervals was computed daily for each schedule.

At the beginning of each session, only the amber changeover key and the houselight were illuminated. A single peck to the changeover key started the VT schedules and illuminated the signal key. The VT schedule in effect at the beginning of each session alternated daily.

Sessions consisted of three consecutive 15-min blocks (excluding time during which reinforcers were delivered) with no indication of changes between blocks. The birds were studied in 3-day cycles. During the first 2 days of the cycle, all three blocks were identical and implemented as described, thus appearing as a homogeneous 45-min session. On every 3rd day of the cycle, everything remained the same except that no reinforcers were delivered during the middle 15-min block of the session. Each condition was in effect for 60 consecutive days (20 3-day cycles). Data recorded were the times at which responses to the changeover key occurred and the times at which reinforcers were delivered.

After completion of the third experimental condition, the birds were placed on complete extinction. Daily 45-min sessions continued as before except reinforcers were never delivered. For each bird, extinction continued until the number of changeovers per session was less than 20% of the mean for the last three *conc* VT VT sessions (seven, four, and five sessions for Birds 15, 16, and 17, respectively).

RESULTS

A series of analyses were conducted in order to answer several questions concerning the molar and molecular effects of reinforcers on choice. First, is typical operant choice behavior (i.e., matching of time allocation to reinforcer distribution) generated and maintained by the present procedure, involving as it does reinforcer-free periods interleaved with periods of *conc* VT VT? Second, is there any difference at the molar level between time allocation in the reinforcer-free and *conc* VT VT periods? Third, what are the effects at the molecular level of reinforcer delivery? More specifically, how do reinforcers affect the duration of the stay during which a reinforcer is delivered, the subsequent stay in that same schedule, and the subsequent stay in the alternative schedule? Finally, how do extended reinforcer-free periods (i.e., extinction) affect the allocation of behavior?

Was Molar Matching Obtained?

For all 3 birds, the relation between time allocation and reinforcer distribution, both overall as well as within both reinforcer-free and *conc* VT VT periods, was well described by the generalized matching equation (Equation 1). Table 1 presents the mean numbers of reinforcers and time allocated to the alternative schedules during the last 30 sessions of each condition for each bird. The middle 15 min of every third session of these 30 sessions included a reinforcer-free period. For these 10 sessions, time allocation is further broken down into allocation during the reinforcer-free and *conc* VT VT periods.

Figure 1 shows the logarithm of the ratio of the times allocated to the two schedules as a function of the logarithm of the ratio of the reinforcers obtained in the two schedules (green/red). The points represent the means of the last 30 sessions of each condition for each bird. As may be seen, the relation between overall time allocation and reinforcer distribution is well described by the generalized matching equation ($Y = 0.84X + 0.04$, $r^2 = 0.89$)[1].

Figure 2 presents the time-allocation data for each bird from those 10 sessions of the last 30 sessions that contained reinforcer-free periods. The logarithms of the ratios of the times in the reinforcer-free periods and the 15 min of *conc* VT VT immediately preceding and following these reinforcer-free periods are both plotted as a function of the logarithms of the reinforcer ratios obtained in the last 30 sessions. (To facilitate comparisons with Figure 1, reinforcer ratios from the last 30 sessions were used; virtually identical results were observed using reinforcer ratios obtained in the 10 sessions containing reinforcer-free periods.)

As may be seen, for each bird, the relations between time allocation and reinforcer distribution for the reinforcer-free and *conc* VT VT periods are nearly indistinguishable from each other. In addition, these relations are also indistinguishable from those observed for the last 30 sessions considered as a whole. For purposes of comparison with Figure 1, the best fitting generalized matching equations based on the data from all 3 birds were $Y = 0.88X$

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[1] The percentage of variance accounted for in the data from a sample overestimates the percentage of variance accounted for in the population. This overestimation increases as the sample size decreases. Consequently, because of the small numbers of data points in the present experiment, all r^2 values have been corrected using the formula *shrunken* $r^2 = 1 - (1-r^2)(n-1)/(n-2)$, where n equals the number of data points (Cohen & Cohen, 1983).

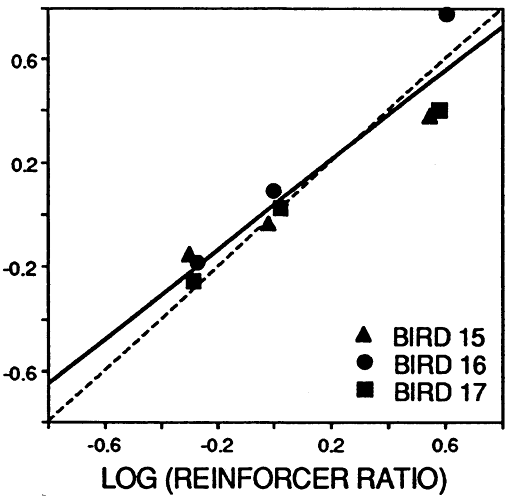

Fig. 1. The logarithm of the ratio of time spent in each schedule (green/red) as a function of the logarithm of the ratio of reinforcers obtained from each schedule. Data are based on the mean of the last 30 sessions of each condition for each bird. The solid line is the best fitting line; the broken line represents perfect matching.

+ 0.04 ($r^2 = 0.85$) and $Y = 0.82X + 0.03$ ($r^2 = 0.89$) for the reinforcer-free and *conc* VT VT periods, respectively. Moreover, as may be seen in Table 2, there was little, if any, difference between the changeover rates for the reinforcer-free and *conc* VT VT periods, or between these rates and those for the last 30 sessions.

How Do Reinforcers Affect Stay Durations?

The immediate effect of a reinforcer was generally to increase the duration of the stay during which it was delivered (i.e., to postpone switching to the alternative schedule). Interestingly, there were no systematic effects either on the immediately following stay at the schedule in which the previous reinforcer was delivered or on the duration of the immediately subsequent stay in the alternative schedule.

The effects of reinforcers on stay durations were analyzed separately for stays preceding, containing, and following a reinforcer delivery. A stay was measured as the time from the peck on the changeover key that switched over to a given schedule to the peck that switched back

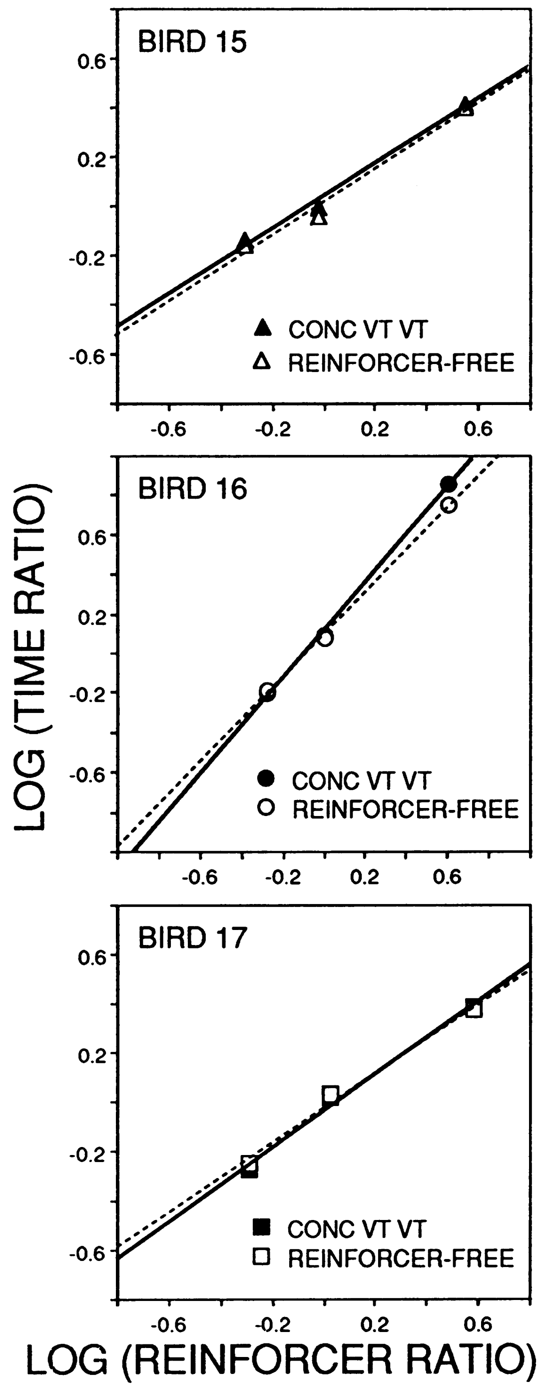

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Fig. 2. The logarithm of the ratio of time spent in each schedule as a function of the logarithm of the ratio of reinforcers obtained from each schedule for each bird. Time data are based on the final 10 sessions in which 15-min reinforcer-free periods were inserted between 15-min periods of *conc* VT VT. Open symbols represent time allocation during reinforcer-free periods; closed symbols represent time allocation during *conc* VT VT immediately preceding and following the reinforcer-free periods. The dotted line is the best fitting line for the reinforcer-free portion of the sessions; the solid line is the best fitting line for the *conc* VT VT portion of the sessions.

Table 2

Changeover rates (CO/min).

	VT schedule		Overall[a]	Reinforcer-free[b]	Conc VT VT[b]
Subject	Green	Red	CO/min	CO/min	CO/min
15	240	120	11.40	11.15	10.83
	107	320	5.36	5.20	4.97
	160	160	8.29	7.35	7.67
16	107	320	5.63	5.16	5.85
	160	160	9.61	7.95	9.21
	240	120	7.65	7.31	8.28
17	160	160	7.61	7.89	7.48
	240	120	6.78	7.60	6.52
	107	320	6.31	6.66	6.11

[a] Mean data from the last 30 sessions.

[b] Mean data from the last 10 sessions that included the reinforcer-free periods.

to the alternative schedule. Four types of stays, illustrated in Figure 3, were computed separately for both the rich and lean schedules of each condition for each bird:

1. *Reinforcer stays* consisted of stays during which a reinforcer was delivered. Reinforcer stays could neither contain more than one reinforcer nor follow a stay in the same schedule in which a reinforcer was delivered. The 3-s period of access to grain was not included in measures of stay duration.

2. *Prereinforcer stays* consisted of stays that immediately preceded a reinforcer stay in that same schedule. Prereinforcer stays could neither contain a food delivery nor follow a stay in the same schedule during which a reinforcer was delivered.

3. *Postreinforcer stays* consisted of stays that immediately followed reinforcer stays in the same schedule. Postreinforcer stays could not contain a reinforcer.

4. *Postreinforcer stays–opposite* consisted of stays that immediately followed reinforcer stays in the alternative schedule. Postreinforcer stays–opposite could neither contain a reinforcer nor be a postreinforcer stay.

Prereinforcer stays provided a basis for comparison of the other three stay types in order to examine the effects of reinforcer delivery on stay duration. Comparisons of stay durations were always made between stays in the same schedule (i.e., rich or lean). Comparisons with reinforcer stays provide a measure of the immediate effects of reinforcers. Comparisons with postreinforcer stays provide a measure of more delayed effects of reinforcers on stays in the same schedule during which the reinforcer was delivered, whereas comparisons with postreinforcer stays–opposite provide a measure of the effects of reinforcers on the duration of stays in the alternative schedule immediately following reinforcer delivery.

The durations of prereinforcer, reinforcer, and postreinforcer stays for Birds 15, 16, and 17 are shown as striped bars in Figures 4, 5, and 6. In general, reinforcer stays were substantially longer than prereinforcer stays. This effect was evident in 15 of the 18 comparisons and represented a 61% increase on average for

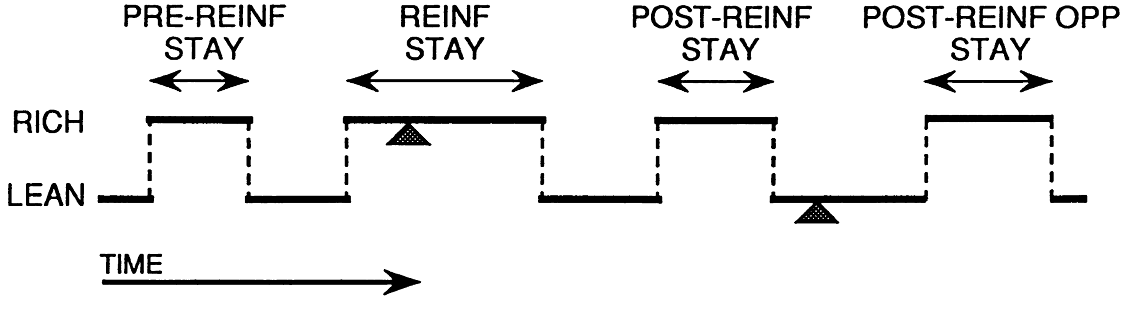

Fig. 3. Schematic representation of the four types of stay durations. Stay types are shown here for the rich VT schedule; an analogous set of stay durations was computed for the lean VT schedule. The dark lines represent time spent in the respective schedule; dashed lines represent alternations between schedules. The two filled triangles represent reinforcer deliveries. The first three stay types are computed with reference to a reinforcer that is delivered in the same schedule, whereas the fourth stay type is computed with reference to a reinforcer that is delivered in the alternative schedule: (a) The prereinforcer stay immediately precedes the stay during which a reinforcer is delivered; (b) the reinforcer stay is the stay during which a reinforcer is delivered; (c) the postreinforcer stay immediately follows the stay in the same schedule during which a reinforcer was delivered; and (d) the postreinforcer stay–opposite immediately follows the stay in the alternative schedule during which a reinforcer was delivered.

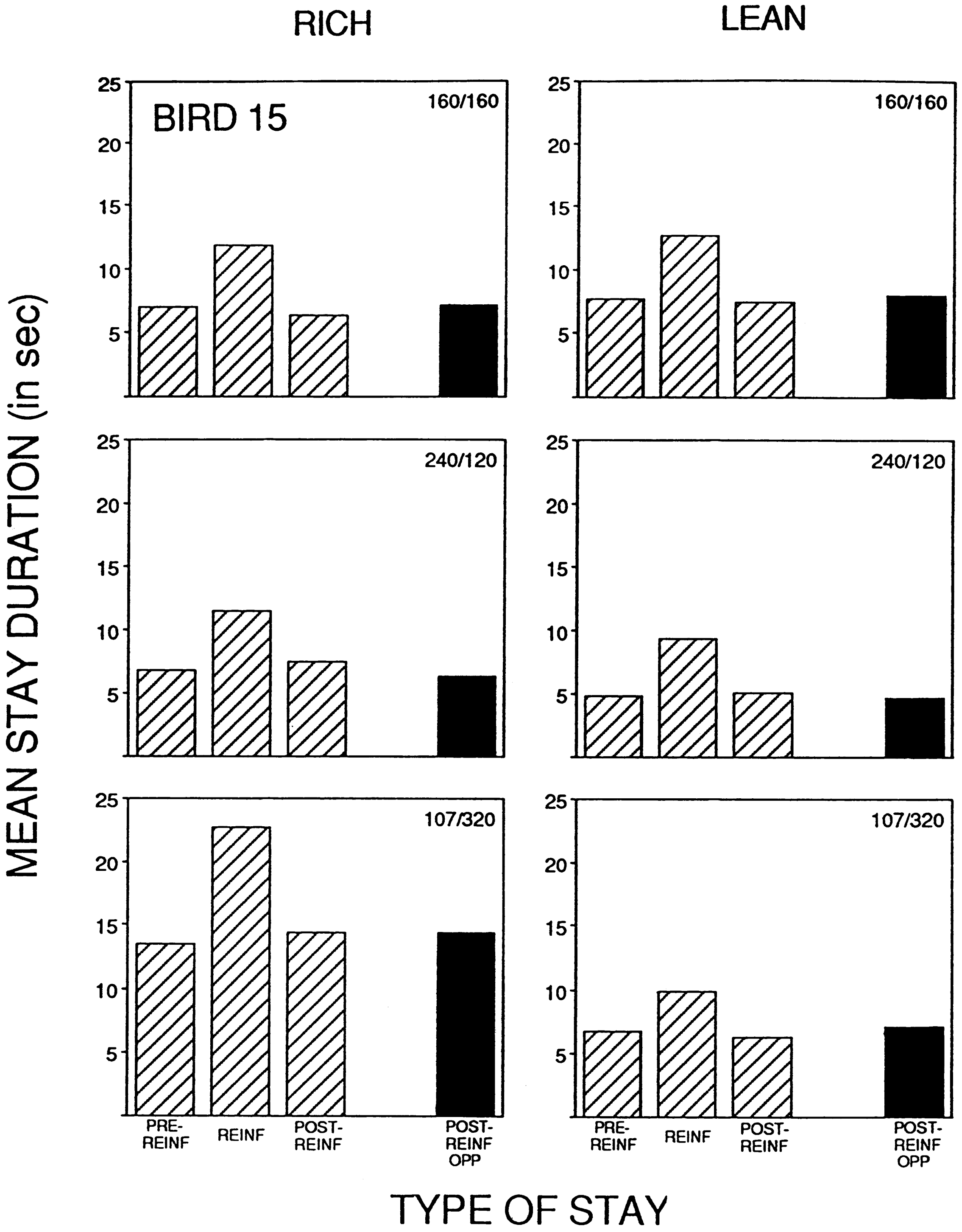

Fig. 4. Mean stay durations for each of the four stay types for Bird 15. Prereinforcer, reinforcer, and postreinforcer stay durations are shown as striped bars; postreinforcer stays–opposite are shown as solid bars. The top row is from the *conc* VT 160-s VT 160-s schedule; the middle row is from *conc* VT 240 s VT 120 s; the bottom row is from *conc* VT 107 s VT 320 s. The panels on the left are for stay durations during the richer VT schedule, and the panels on the right are for stay durations during the leaner VT schedule. Data are from the last 20 sessions that did not include the reinforcer-free manipulation.

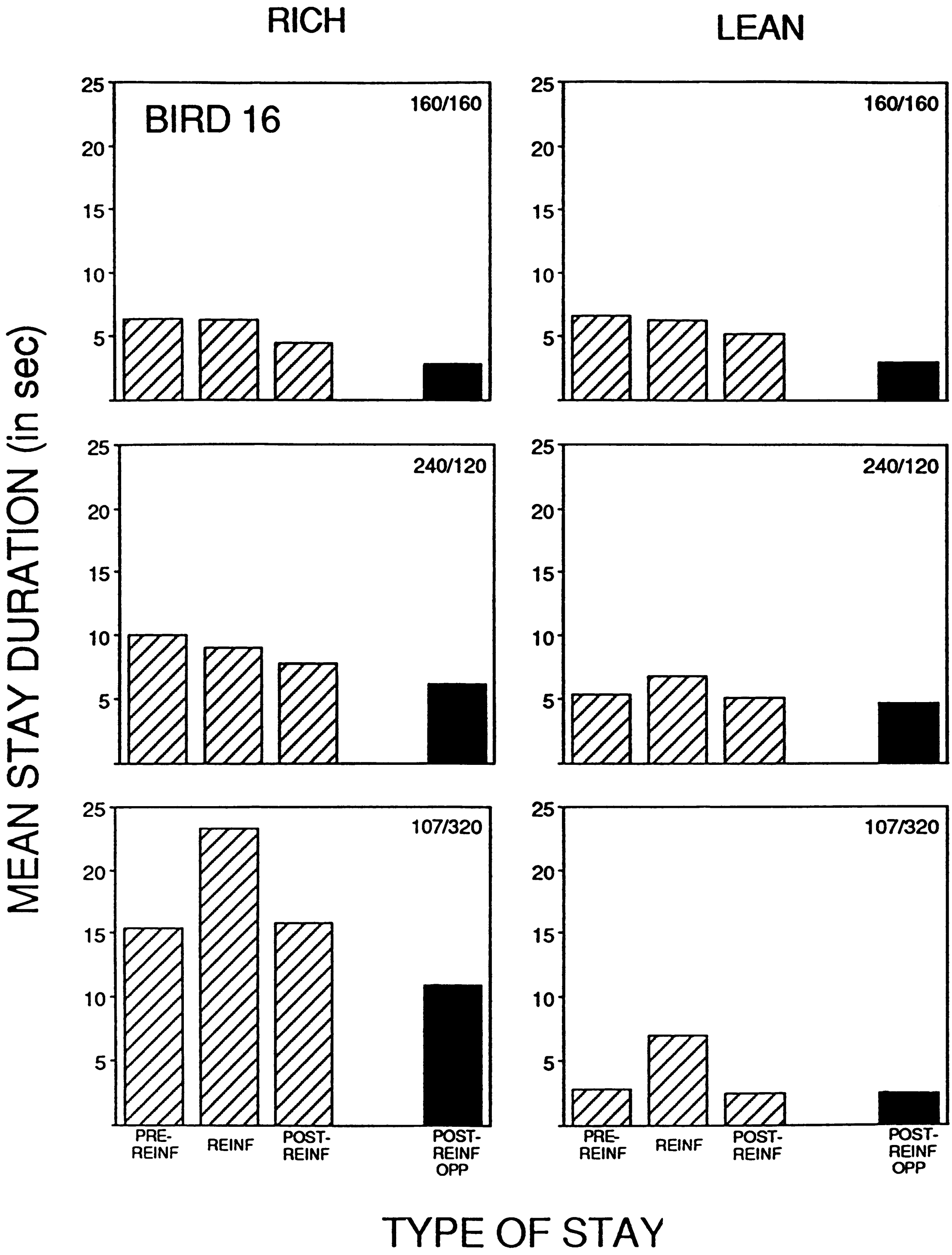

Fig. 5. Mean stay durations for each of the four stay types for Bird 16. See Figure 4 for explanation.

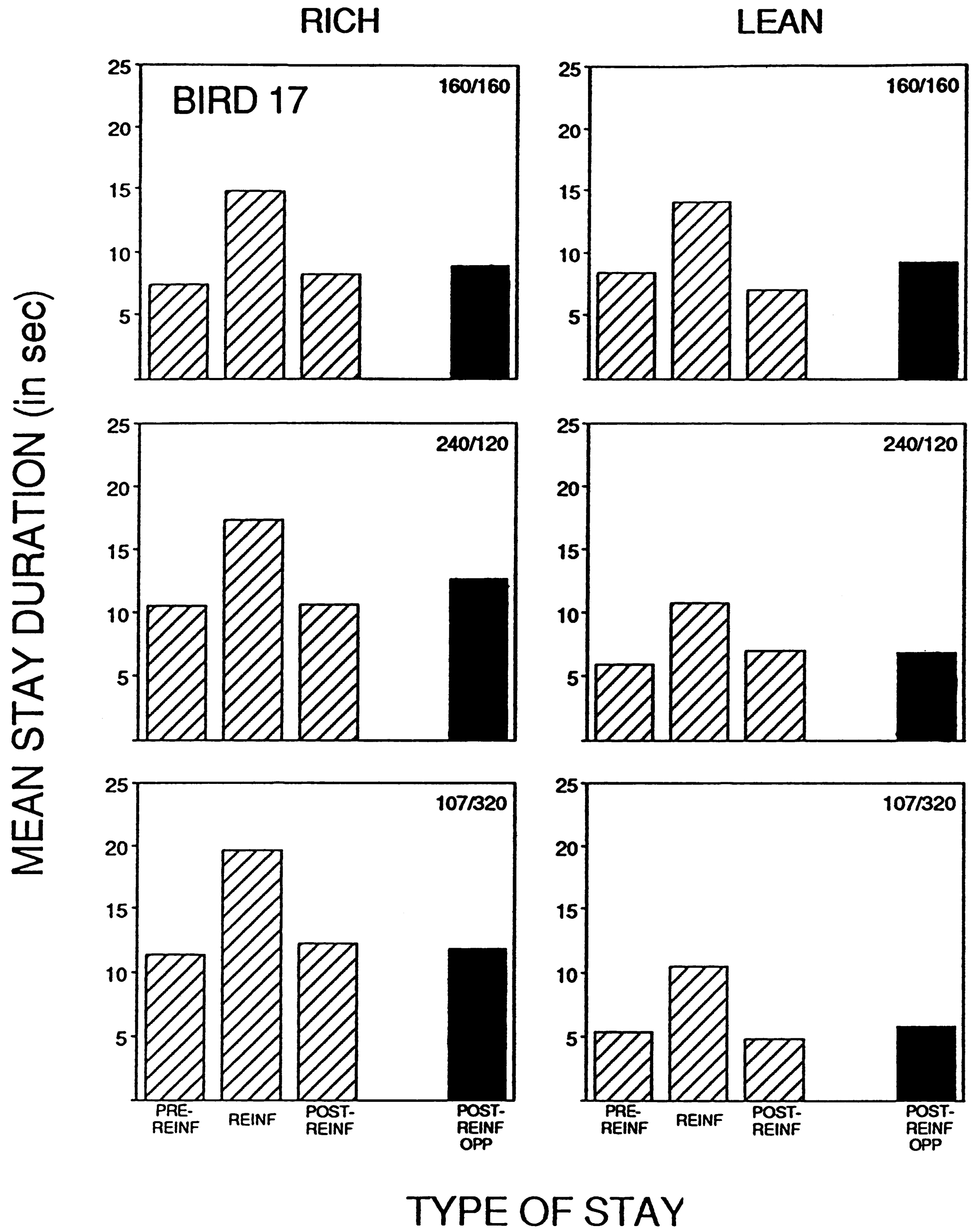

Fig. 6. Mean stay durations for each of the four stay types for Bird 17. See Figure 4 for explanation.

all birds on all schedules. Surprisingly, postreinforcer stays were generally the same duration as prereinforcer stays, suggesting that the effect of a reinforcer delivery was primarily on the stay in which it occurred. Postreinforcer and prereinforcer stay durations were approximately equal for 2 of the birds; the ratio was 1.00 for Bird 15 and 1.02 for Bird 17. For Bird 16, the ratio of post- to prereinforcer stay durations was 0.86, indicating that postreinforcer stays were actually shorter than prereinforcer stays.

The reinforcer stays were subdivided into time to the delivery of a reinforcer and time after the reinforcer so that the time spent following a reinforcer delivery could be compared with the duration of prereinforcer stays (which did not contain reinforcers). If stay durations were determined by a simple Markov process (Heyman, 1979), then the mean time after reinforcers would equal the mean duration of stays during which reinforcers were not delivered. Likewise, if reinforcer delivery merely reset some clock that timed stay durations, then the mean time after the reinforcer would again equal the mean duration of stays during which reinforcers were not delivered. For 2 of the 3 birds, the time after the reinforcer was delivered was longer than the duration of the prereinforcer stay. Across all conditions, the time following reward delivery was 15.2% and 27.1% greater than the prereinforcer stay duration for Birds 15 and 17, respectively, and these differences were statistically significant ($ts = 6.16$ and 6.82; both $ps < .01$). (For Bird 16, time following a reward was not reliably different from prereinforcer stay duration.) Thus, for 2 of the 3 birds, the present results are inconsistent with both a resetting-clock model and a simple Markov model in which the probability of terminating a stay is stationary and unaffected by reinforcer delivery.

As just noted, the time following a reinforcer delivery was generally greater than the prereinforcer stay duration. This argues against the idea that reinforcer stays are longer than stays without a reinforcer delivery merely because longer stays in a schedule increase the probability of reinforcer delivery. Instead, the data suggest that reinforcer deliveries are a cause, rather than a consequence, of longer stay durations. Consistent with this interpretation, the average time from the beginning of a reinforcer stay until reinforcer delivery was less than the average prereinforcer stay duration for every bird in every condition.

In addition to examining the effects of reinforcer delivery on the duration of stays in the same schedule, the effects on stays in the alternative schedule were also examined. The durations of postreinforcer stays–opposite are shown for each bird as solid bars in Figures 4, 5, and 6. As may be seen, there was no consistent effect of reinforcer delivery on the duration of postreinforcer stays–opposite relative to the duration of prereinforcer stays in the same schedule: For 1 bird (15), there was virtually no change in stay length following a reinforcer delivery in the opposite schedule; for 1 bird (16), there was a decrease in stay length; and for 1 bird (17), there was an increase in stay length following reinforcer delivery in the opposite schedule.

How Does Extinction Affect Time Allocation?

As long as the birds continued to change over at a reasonable rate between the two schedules, relative time allocation in extinction remained virtually the same as that observed on the preceding *conc* VT VT schedules of reinforcement. Figure 7 presents the relative time allocation for the last three sessions during which reinforcers were delivered and for the first three sessions of extinction. Note that for each bird, extinction followed a different *conc* VT VT schedule of reinforcement. Relative time allocation in extinction continued to approximate the reinforcer distribution obtained in the previous condition. Importantly, for the 2 birds (16 and 17) for whom extinction followed exposure to unequal reinforcement schedules, time allocation in extinction showed no indication of any trend toward indifference, even though number of changeovers had decreased substantially. By the third session of extinction, the number of changeovers for both birds was approximately one third of that during the final three sessions during which reinforcers were delivered.

In addition, a more molecular analysis of the behavior of Birds 16 and 17 in extinction was conducted. In order to examine possible changes in relative time allocation over the course of individual sessions, running means were calculated based on 40 stays (20 in each schedule). Figure 8 presents time allocation as a function of time through the session for the last day during which reinforcers were deliv-

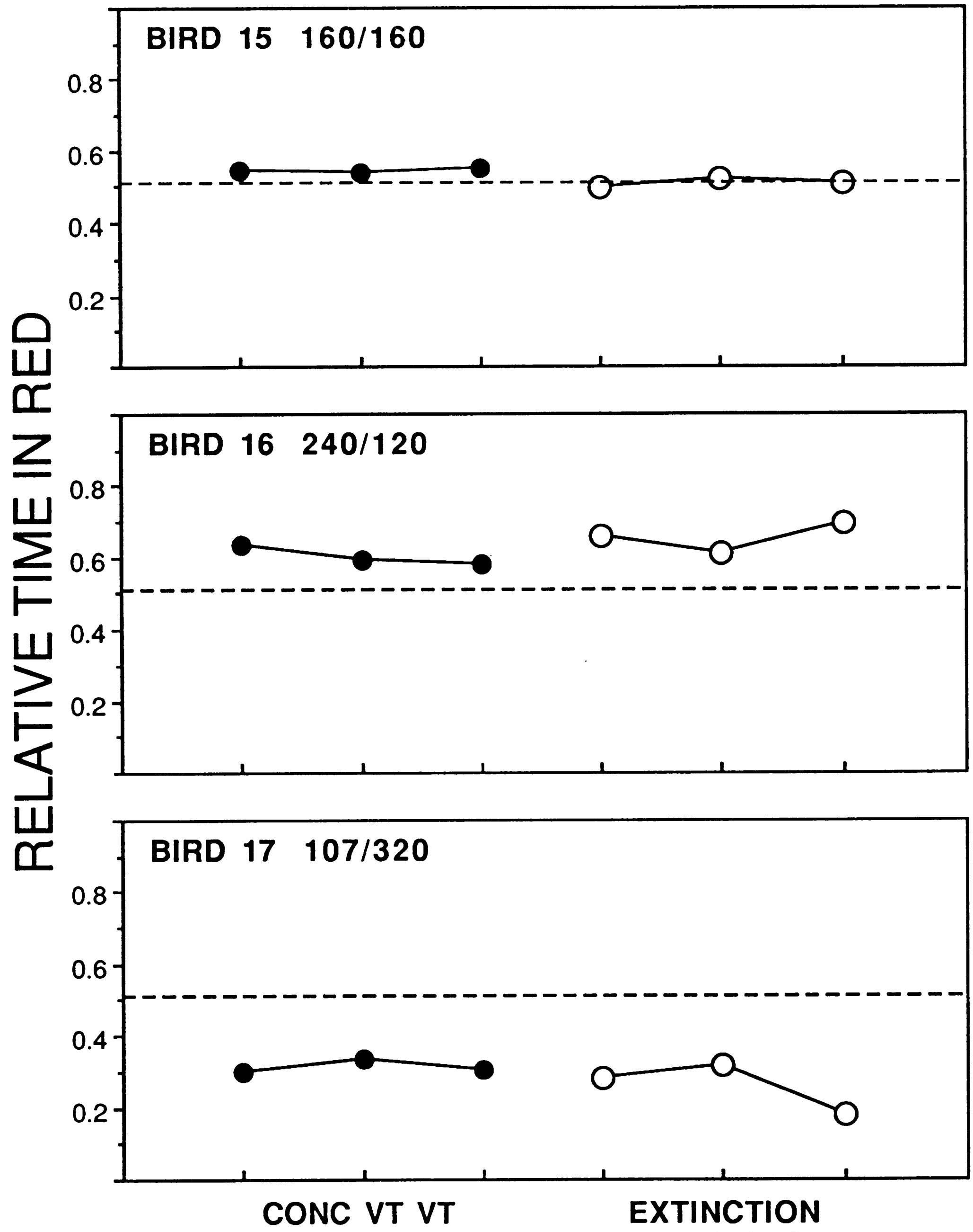

Fig. 7. Relative time spent in red for each of the final three sessions during which reinforcers were delivered (*conc* VT VT; closed symbols) and for each of the first 3 days of extinction (open symbols). Each panel presents the data for a different bird.

ered and for the first 2 days of extinction for Birds 16 and 17. There were no systematic changes in the within-session pattern of time allocation between *conc* VT VT and extinction and no trend toward indifference within the extinction sessions, thus paralleling the time-allocation results for the sessions taken as a whole.

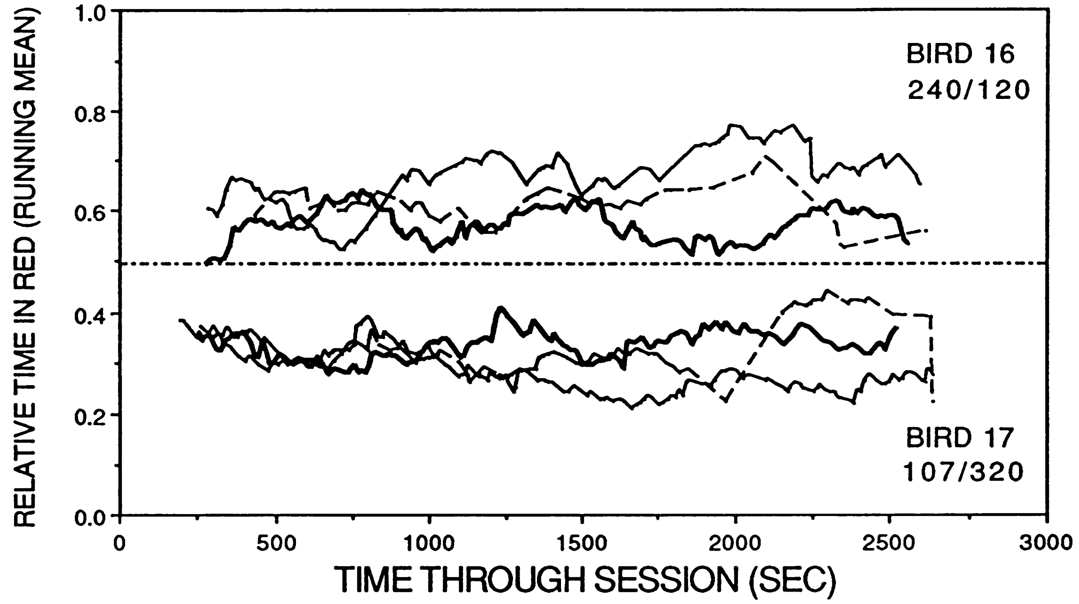

Fig. 8. Relative time spent in red throughout the final session during which reinforcers were delivered (dark solid lines) and during the first two sessions of extinction (Session 1: thin solid lines; Session 2: broken lines). Running means based on 40 stays (20 in the red and 20 in the green) are shown. Data for Bird 16 are shown in the upper panel, and data for Bird 17 are shown in the lower panel.

DISCUSSION

The results from the present experiment suggest that reinforcer deliveries have two distinct effects on temporal aspects of choice behavior, a short-term and a long-term effect. The short-term effect is apparent from changes in molecular measures (i.e., stay durations). Each reinforcer increases the duration of the visit during which it is delivered. However, a reinforcer delivery has little consistent effect either on the immediately following stay in the alternative component or on the subsequent stay in the component during which the reinforcer had just been delivered (see Figures 4, 5, and 6). The long-term effect is apparent from changes in molar measures (i.e., relative time allocation). The cumulative effect of reinforcers is to influence differentially the relative amount of time spent in each component of a concurrent schedule.

Whereas the short-term effect seems to last a matter of seconds, the long-term effect lasts for many minutes, if not hours or days, following reinforcer deliveries. When 15-min reinforcer-free periods were inserted into the middle of every third experimental session, time allocation during these periods was indistinguishable from that during periods of reinforcer delivery (see Figure 2). Moreover, relative time allocation during the first couple of days of extinction showed little change from that during the preceding sessions during which reinforcers were delivered (see Figures 7 and 8).

These findings regarding time allocation following response-independent *conc* VT VT training are in agreement with those of Myerson and Hale (1988), who found that response allocation remained relatively unchanged in extinction following response-dependent *conc* VI VI training. Thus, both time and response allocation may show little change even while changeover and response rates decrease. Such stability of preference in extinction is inconsistent with melioration theory (Herrnstein & Vaughan, 1980). Melioration predicts that relative time allocation will approach indifference as time passes without any reinforcers being delivered. This is because organisms are posited to base their preference on a comparison of the local rates of reinforcement for concurrently available schedules. As time passes without any reinforcers being delivered, local reinforcement rates approach zero, and thus preference must approach indifference. Of course, when changing over ceases, relative time allocation (trivially) must equal zero or one; therefore, tests of melioration's prediction of indifference must be conducted early in extinction.

The critical feature of melioration theory that leads to the prediction of indifference in extinction is the assumption that organisms continuously calculate local rate of reinforcement during each stay at a schedule. How long it takes for indifference to be reached would, of course, depend on the size of the time window over which local rate is averaged. In fact, how long it takes for the organism to respond to *any* changes in reinforcement rate would depend upon the size of the time window. One might argue that this time window is long enough to bridge the 15-min reinforcer-free periods. However, in order to explain the stability of preference during extinction in the present study, melioration theory would need to assume a time window that could bridge several 45-min sessions. An organism with such a window should not modify its time allocation within the first session following a change in reinforcement rates. Yet organisms clearly show such rapid changes in preference (e.g., Killeen, 1972; Krebs, Kacelnik, & Taylor, 1978; Myerson & Hale, 1988). Thus, the present findings constitute a major challenge to melioration theory as currently formulated. (Although current formulations of melioration theory appear to assume an averaging process for the determination of local reinforcement rate that operates continuously during a stay at a particular schedule, it is possible to imagine an averaging process that operates only upon reinforcer delivery. At that time, the average local rate for one or both alternatives would be updated. Such a mechanism would not update in the absence of reinforcer deliveries, i.e., during extinction, thus leading to the prediction that extinction would not result in a change in preference.)

The present results represent two paradoxes to be resolved. First, given that a reinforcer has an immediate effect on stay duration, how can time allocation during periods in which reinforcers are not delivered be so similar to that during periods of reinforcer delivery? The answer to this question is suggested by a comparison of the reinforcer-free periods with the immediately preceding and following *conc* VT VT periods. Whereas the overall rates of reinforcement during *conc* VT VT averaged 0.67 per minute for all birds in all conditions, the mean changeover rate was 7.44 per minute. Thus, approximately 90% of the stays did not include a reinforcer delivery, and consequently the increased duration of reinforcer stays had relatively little impact on time allocation. Consistent with this interpretation, the mean changeover rate was 7.36 per minute during the reinforcer-free periods, virtually unchanged from the rate during periods when reinforcers were delivered.

Second, given that reinforcers appear to affect only the durations of the stays in which they are delivered and not the immediately subsequent stays in either component, how do they determine molar allocations of time to the components? Reinforcers may well affect the durations of immediately subsequent stays, but the change due to each reinforcer may be too small to detect. This, of course, assumes that a molecular mechanism underlies matching. However, Nevin (1979) has argued that because molar matching is observed in conjunction with different sequential response patterns, molar matching is not reducible to more molecular processes. Thus, matching may be the result of a probabilistic, molar process (Baum, 1973), and several such models have been proposed (e.g., Rachlin, Battalio, Kagel, & Green, 1981; Staddon & Motheral, 1978). Although the present study was not designed as a test of molecular models of matching, our results are consistent with a molar approach in that, although there is order at the molecular level, this order does not contribute to an explanation of matching.

It should be noted, however, that the present study focused on steady-state choice behavior; different patterns of behavior might be observed in transition, at which point individual reinforcers may have larger effects. Mazur has recently examined molecular response patterns during transition states on *conc* VR VR (Mazur & Ratti, 1991) and on a discrete-trial procedure in which two keys were associated with different probabilities of reinforcement (Bailey & Mazur, 1990). In both studies, a recency effect was observed, such that there was a short-lived increase in the probability of continuing to respond on the same key immediately following a reinforcer and/or a decreased probability of responding on the same key following a key peck that did not result in reinforcer delivery. This recency effect appears to correspond to the short-term effect of reinforcer delivery on stay durations in the present study. However, its short duration (one, or at most two, responses in the Mazur studies) means that it could not account for the molar change in preference that actually characterizes the transition state.

A number of experiments have demonstrated that the discriminative control exerted by reinforcer delivery also has short-term and long-term aspects (e.g., Shimp, 1976; Williams, 1991). In these studies, molar reinforcement contingencies have often been pitted against local contingencies. Local control, when it emerges, appears to be superimposed on short-term perseveration or recency effects (e.g., Williams, 1991), that is, the tendency to repeat just-reinforced responses. This tendency occurs even in the absence of differential local contingencies (Evenden & Robbins, 1984; Morgan, 1974) and represents converging evidence for a short-term strengthening effect of reinforcer delivery.

The present findings, taken together with those of Mazur and his colleagues (Bailey & Mazur, 1990; Mazur & Ratti, 1991) and others, demonstrate that reinforcement has both short-term and long-term effects on ratio-like and interval schedules, with discrete-trial and free-operant procedures, and in transition and steady states. In addition, short-term and long-term effects are observed regardless of whether responses or stay durations are the dependent measure. Moreover, similar results are obtained on interdependent *conc* VI VI schedules (e.g., Menlove, 1975). The fact that consistent results have been obtained in such a variety of situations and with different measures of behavior testifies to the robustness of the observed phenomena.

Mazur and his colleagues have raised the question of whether the short-term and long-term effects of reinforcers are due to the same underlying mechanism or whether two separate processes are involved. Their findings do not provide an answer to this question, nor do ours, and the issue remains an important one for future studies to address. Regardless of whether there are two separate reinforcement mechanisms or not, however, both the short-term and long-term effects of reinforcement are of interest in their own right.

The present study suggests new experimental and analytic approaches to these issues. The fact that preference and switching rate remain stable during interpolated reinforcer-free periods is not only of theoretical interest but also provides a potentially useful preparation with which to examine choice in the absence of short-term reinforcement effects. The present findings demonstrate that temporal measures of steady-state choice behavior reveal robust and orderly phenomena at the molecular level as well as at the molar level. Although the present results leave unresolved certain theoretical questions regarding the relation between molecular and molar phenomena, between transition and steady-state performances, and between short-term and long-term reinforcement effects, our findings nevertheless serve to constrain possible theoretical explanations and testify to the fundamental nature of the issues raised.

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