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LOCAL CONTRAST IN BEHAVIOR ALLOCATION DURING MULTIPLE-SCHEDULE COMPONENTS

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Allocation of responses between two keys was studied during two alternating multiple-schedule components. Responses were recorded in successive quarters of each component. Variable-interval reinforcer schedules on the two keys were constant throughout the experiment for one (constant) component and were varied over conditions on one key for the other, producing changes in reinforcer ratios for the varied component. Behavior allocation for the first quarter of the constant component was inversely related to varied-component reinforcer ratios, a form of local contrast, but this relationship was not observed later in the component. During the first quarter of the varied component, slopes of matching lines were high and decreased later in the component. It is argued that this form of local contrast cannot be explained in terms of reallocation of extraneous reinforcers between components, and that the matching law for concurrent operants does not capture some sources of control over behavior allocation. A simple extension of the matching law is offered that adequately describes behavior changes during both components. A version of this formulation can predict contrast effects in absolute response rates.

Key words: local contrast, multiple schedules, concurrent schedules, reallocation theory, matching law, key peck, pigeons

Local contrast is a systematic change in behavior over successive subintervals of a multiple-schedule component, and was first studied systematically by Nevin and Shettleworth (1966). Positive local contrast is observed when one component arranges reinforcers at a higher rate than the other component, and refers to an elevation of responding at the beginning of the higher valued component relative to the rate at the end of the same component (Malone, 1976) or, alternatively, relative to the rate at the beginning of the same component in a baseline multiple-schedule condition (Arnett, 1973; McLean & White, 1981). Negative local contrast is simply the reverse pattern of response-rate change over subintervals, and is found in the lower valued of two components.

Local contrast may contribute to other contrast phenomena in multiple schedules, including behavioral contrast. Behavioral contrast is a reverse change in response rate in a constant multiple-schedule component that occurs when the reinforcer rate in an alternated component is varied (see Williams, 1983, for a review). Behavioral contrast is studied using response rates averaged over the whole of the constant component rather than rates in subintervals, as is the case with local contrast, but may be enhanced by local contrast effects at the beginning of the constant component.

An important feature common to all contrast effects is the dependence of behavior in one component on reinforcement conditions in a temporally distant component; this is generally taken as evidence for interaction among temporally separate components in determining absolute response rate. Contrast effects may therefore have important implications for the more general question of which features of an organism's environment control its behavior. However, McLean and White (1983) and McLean (1988) have argued for an interpretation that differs from the usual one of direct interaction of components over time, and have proposed an alternative strategy for the study of contrast effects.

Specifically, McLean and White questioned whether temporally distant components interact directly at all. They suggested, as did Staddon (1982), that contrast effects in absolute

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response rate may result from changes in the availability of extraneous reinforcers, which are obtained by the subject contingent on behavior other than performing the defined multiple-schedule response. For example, a reduction in extraneous reinforcement in a component would reduce the amount of time engaged in "other" behavior in that component and result in an increase in the absolute rate of the defined operant. (See McLean & White, 1983, and Staddon, 1982, for discussions of the conditions under which extraneous reinforcers may be "reallocated" between components.)

The reallocation account of contrast differs from the traditional view in that it suggests that the apparent direct interaction of components in multiple schedules is actually mediated by changes to an additional, unconsidered variable during the (otherwise) constant component. If absolute-rate contrast is caused by changes in simultaneously available extraneous reinforcement, as Staddon and McLean and White suggested, then its basis is in *concurrent* (not successive) interaction, and, in that case, the major source of evidence for direct interaction of reinforcement schedules over time would be undermined.

An alternative strategy for studying contrast is to arrange two response alternatives during each multiple-schedule component (i.e., a multiple-concurrent schedule). Instead of examining changes in absolute response rate on a single key or lever, contrast is studied by examining changes in the allocation of behavior between two concurrently available responses during a constant multiple-schedule component. In the alternated component, the ratio of reinforcers on the two keys is varied over conditions, and contrast is observed as an inverse relationship between behavior allocation between keys in the constant component and reinforcer ratios in the varied component (see McLean, 1988, and Nevin, Mandell, & Whittaker, 1978, for studies of contrast with this procedure).

A major advantage to using behavior allocation as a dependent measure in contrast studies is that allocation has been found not to depend on alternative reinforcement in the way that absolute rate does. Consequently, studying response relativity within a constant component offers a strategy for studying temporal interaction independently of possible changes in extraneous reinforcement. The evidence suggesting that allocation will be independent of changes in extraneous reinforcement comes from studies in which reinforcement is constant for two concurrently available responses and is varied for a third (Davison, 1982; Davison & Hunter, 1976). In these studies, the distribution of responses between the two constant schedules was invariant over conditions in which reinforcer rate on the third alternative was manipulated. Assuming extraneous reinforcers work similarly to those from the third schedule in these studies, changes in extraneous reinforcement (reallocation) in components of the multiple-concurrent schedule will not influence response allocation between two keys. (However, it may affect *absolute* response rates on the two keys proportionately and thus produce absolute-rate behavioral contrast.) When contrast is studied in this alternative procedure, however, evidence of it in the data is questionable, suggesting that contrast may only occur reliably with response measures that are likely to be affected by changes in extraneous reinforcement. McLean (1988) used response allocation between two keys as a measure of contrast in several series of multiple-schedule conditions. Despite use of conditions that are thought to maximize contrast (at least when absolute response rates are studied), McLean found no evidence of contrast in behavior allocation and argued that this result constituted indirect evidence for the reallocation hypothesis offered by Staddon and by McLean and White.

The present study addressses the question of whether local contrast can be studied using behavior allocation rather than absolute response rate. Although local contrast may contribute to behavioral contrast, as noted above, it is not generally thought that the two forms of contrast are the result of the same behavioral process (see, e.g., Williams, 1989) so the failure of behavioral contrast in McLean's study does not mean that local contrast cannot be analyzed this way. In this study, which used the same general procedure as McLean (1988), two keys were present during each multiple-schedule component, and responses were recorded in successive component subintervals. Over conditions, reinforcer rates were constant for both keys in one component and were varied over conditions for one key in the alternated component. Local contrast was studied by measuring changes over subintervals in the way responses were distributed between the two keys.

METHOD

Subjects

Four homing pigeons, each with previous experience in multiple-concurrent schedules of reinforcement, served as subjects. All pigeons were maintained at 80 ± 5% of their free-feeding weights by food reinforcers obtained during experimental sessions and supplementary feed given at the end of the day's running schedule. Water and grit were continuously available in home cages.

Apparatus

A lightproof, sound-attenuating chamber (35 cm by 33 cm by 34 cm) contained the interface panel. Two 2.5-cm-diameter response keys were 25 cm from the floor and each 9 cm to either side of the center of this panel. A hopper was centrally located in the interface panel and 8 cm from the floor. Each key was illuminated red (Component 1) or green (Component 2) and pecks exceeding about 0.2 N produced 0.05-s offset of the keylight. Reinforcement consisted of 2.5-s access to wheat, during which the hopper was illuminated white and both keys were dark. A ventilation fan at the rear of the chamber helped mask extraneous sounds. Solid-state programming apparatus, located in an adjoining room, scheduled all experimental events. An electronic datalogger recorded responses in subintervals of components, starting with the 25th session in each condition.

Procedure

Responses on two keys were reinforced according to independent variable-interval (VI) schedules (Fleshler & Hoffman, 1962) at different rates according to whether the keys were illuminated red or green. Variable-interval timing for a component stopped as soon as components changed, at 100-s intervals, and reinforcers not obtained by the end of components were not canceled. Responses were recorded separately in four 25-s subintervals of components. A response on either key that directly followed a response on the alternative key constituted a changeover and was not reinforced. Changeovers initiated a 1.5-s changeover delay, during which no responses were reinforced. The delay was reinitiated if another changeover occurred. The concurrent schedule in Component 1 always arranged reinforcers at 20 per hour on the left key and 10 per hour on the right key. In Component 2 the scheduled reinforcer rate on the right key was always 10 per hour and on the left key it was varied over conditions. Schedule combinations in each of the five experimental conditions are given in Table 1.

Table 1

Variable-interval schedules (in minutes) for left and right keys in Conponents 1 and 2, for each experimental condition. Conditions are given in order of exposure, with the number of training sessions given for each condition.

	Schedule combinations				
	Component 1 (constant)		Component 2 (varied)		
Condition	Left	Right	Left	Right	Sessions
1	VI 1.5	VI 3.0	VI 1.5	VI 3.0	30–43
2	VI 1.5	VI 3.0	VI 6.0	VI 3.0	56
3	VI 1.5	VI 3.0	VI 3.0	VI 3.0	38
4	VI 1.5	VI 3.0	VI 0.75	VI 3.0	35
5	VI 1.5	VI 3.0	VI 1.5	VI 3.0	47

Conditions were maintained for at least 25 sessions and until a stability criterion had been met on the left key. The criterion was that, for each of five consecutive sessions, the proportion of all left-key responses that occurred in Component 1 did not deviate from the mean proportion over those five sessions by more than .025. However, because the phenomena of interest here concern concurrent performances, stability judgments were sometimes not accepted because clear trends were still apparent in behavior allocation between keys in one or the other component. When the response proportions for all subjects were judged stable, the VI schedules were changed and the performances of the last five sessions were used as steady-state data. The only exception to this was Condition 1, in which training was temporarily discontinued for Birds A1 and A4 (stable after 30 sessions) and A3 (stable after 32 sessions) while A2 reached stability. For Condition 1, steady-state data are those from the sessions that satisfied the stability criterion.

Performance measures obtained separately for Components 1 and 2 were the response and reinforcer rates on each key. Response rates

Table 2

Responses per minute and reinforcers per hour for each bird in each condition. Measures are given separately for each key during each component.

		Responses				Reinforcers			
		Component 1		Component 2		Component 1		Component 2	
Bird	Condition	Left	Right	Left	Right	Left	Right	Left	Right
A1	1	137.5	29.4	118.6	39.2	37.9	15.1	40.6	16.1
	2	98.8	40	58.9	72.4	37.3	14.5	9.2	19.9
	3	95.1	33.1	64.8	51.2	43.3	18.2	21.1	19
	4	99	37.9	125.7	33.3	38	21.9	82.5	20.3
	5	93.5	40.1	95.8	32	35.8	19.7	41.6	17.2
A2	1	63.3	48.3	82.5	33	37.9	19.3	41.1	17.2
	2	83.9	35.7	31.5	54.7	36.9	20.3	7.1	19.3
	3	70.2	37.4	49	42.2	37.4	19.2	18.5	20
	4	73.1	34.6	89.4	28.5	36.8	18.2	79	18.7
	5	81.8	39.7	76.3	35.9	43.8	18.2	37.4	17.6
A3	1	76.1	60.2	69.1	67.2	35.3	21.8	34.3	22.3
	2	82.8	68.2	55.2	73.4	40.6	19.3	9.7	17.8
	3	67.9	77.2	55.5	75.2	35.2	16.6	17.9	19
	4	83	73.8	92.2	62.7	35.8	20.3	76.3	19.7
	5	69.1	83.7	71.4	81	38	20.8	33.8	21.3
A4	1	97.6	49.5	100.6	47.7	39.5	17.2	41.2	18.7
	2	116.6	42.5	59.4	54.2	39.1	20.3	11.2	18.4
	3	110.4	44.4	69.3	53.8	37	21.3	18.5	19
	4	95.1	37.9	111.8	40.9	36.3	16.1	75.1	18.1
	5	82.9	46	93.9	52.3	36.9	19.2	37.9	18.7

were calculated separately for subintervals of components by dividing the number of responses on a key during a subinterval by a time base for the component subinterval. The time base was total time in a component less total reinforcement time for that component, and was divided by four to give a subinterval time base.

RESULTS

Table 2 gives the response and reinforcer rates for each key in each component, averaged over all subintervals. Data for individual subintervals are given in the Appendix. Table 2 shows that, across conditions, reinforcers obtained during the constant component (Component 1) were approximately constant as arranged and were consistently distributed between keys. The behavior-allocation results relating to behavioral contrast and local contrast in the constant component and concurrent performances in subintervals of the varied component are described separately below under separate headings.

Behavioral Contrast

Study of ratios comprising response rates averaged over all four subintervals would reveal any behavioral contrast in behavior allocation during the constant component. Figure 1 shows behavior allocation for the constant component (right panels) and for the varied component (left panels), both plotted as a function of changes in the reinforcer ratio in the varied component. Behavior allocation is presented as base 10 logarithms of response ratios (rates on the left key divided by rates on the right), and reinforcer ratios are treated in the same way. Least squares regression lines are given with the origin indicated by a cross, and their equations and standard errors of estimate are given for each bird. The regression lines for varied-component performances (left panels) are plots of Baum's (1974) generalized matching relation for concurrent schedules, written for Component 2:

$$\log_{10}\left(\frac{P_{L2}}{P_{R2}}\right) = a \log_{10}\left(\frac{R_{L2}}{R_{R2}}\right) + \log_{10}c. \qquad (1)$$

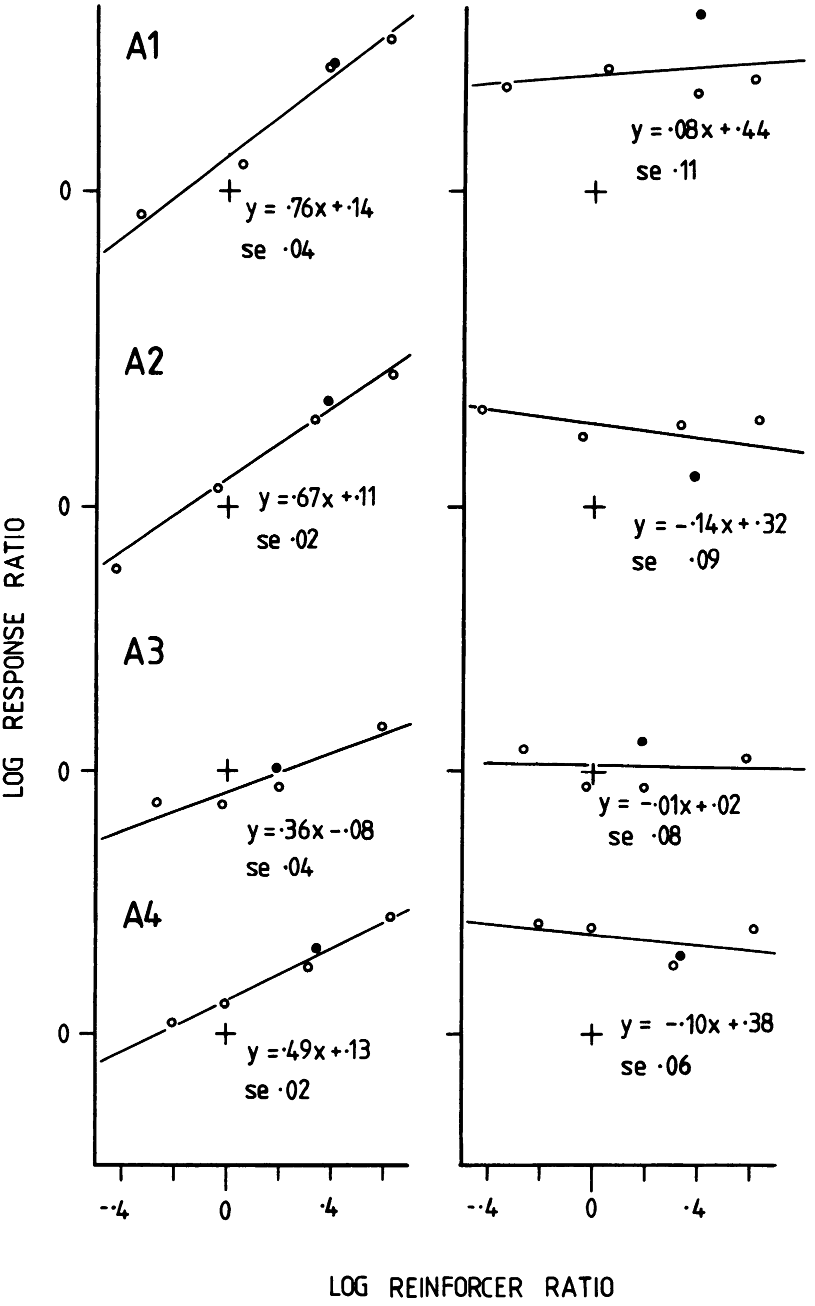

Fig. 1. Base 10 logarithms of response ratios (left/right) during Components 1 and 2 plotted as a function of log reinforcer ratios during Component 2. The left side of the figure gives performances in Component 2 (varied component), and the right side gives those in Component 1 (constant component). Equations of least squares regression lines are given for each bird, with standard errors of estimate, near the origin (cross). The filled circle gives performance in Condition 1.

In Equation 1, P and R represent response and reinforcer rates, respectively, and the subscripts identify the key (left or right) and component (in this case, Component 2) in which they occurred. The slope of this linear function (a) quantifies changes in behavior allocation as a function of changes in reinforcer ratios (sensitivity), and the intercept (log c) quantifies bias in behavior allocation favoring the left key. The slopes of regression lines in Figure 1 are a little lower than those usually found in concurrent schedules, which are in the range 0.80 to 1.0 (Baum, 1979), but there is clear sensitivity of behavior allocation in a component to changes in reinforcer ratios in the same component.

For behavior in Component 1, Equation 1 predicts constant response ratios across conditions because the reinforcer ratio in Component 1 (R_{L1}/R_{R1}) was invariant. However, if behavior allocation in Component 1 depended on the temporally distant reinforcer ratio R_{L2}/R_{R2} (i.e., direct interaction), then changes in Component 1 response ratios would be expected. Specifically, for behavioral contrast in response allocation, an inverse relationship is expected between constant-component response ratios and varied-component reinforcer ratios. An extension to Equation 1 describes this additional source of control over behavior allocation in Component 1:

$$\log_{10}\left(\frac{P_{L1}}{P_{R1}}\right) = a \log_{10}\left(\frac{R_{L1}}{R_{R1}}\right) + n\left[\log_{10}\left(\frac{R_{L2}}{R_{R2}}\right) - \log_{10}\left(\frac{R_{L1}}{R_{R1}}\right)\right] + \log_{10}c. \quad (2)$$

Equation 2 introduces a new term into the generalized matching relation. In Equation 2, log response ratios in Component 1 depend on the Component 1 log reinforcer ratios [$\log_{10}(R_{L1}/R_{R1})$] as is stated in Equation 1, and also on the difference between the log reinforcer ratios in the two components [$\log_{10}(R_{L2}/R_{R2}) - \log_{10}(R_{L1}/R_{R1})$]. The parameter a quantifies sensitivity to same-component reinforcers, and n quantifies sensitivity to the difference between component reinforcer ratios. In a condition in which the two components arrange the same reinforcer ratio, Equation 2 reduces to Equation 1. This equation is similar to McLean and White's (1983) Equation 11 (see also McLean, 1988, Equation 4), and the parameters a and n have the same interpretations as in that equation. The present version is different in some respects that will be discussed later.

Inspection of Equation 2 shows that in the present conditions, where R_{L1}/R_{R1} is constant, n quantifies the influence of reinforcer ratios in the varied component over response ratios in the constant component. Thus, for Component 1 in this experiment the interpretation of n is clear (i.e., component interaction), and the slopes of regression lines in the right panels of Figure 1 directly estimate its value for individual performances. Negative slopes for Birds A2 and A4 are consistent with behavioral contrast in response ratios, but the performances of Birds A1 and A3 argue against contrast as a general conclusion. These results are therefore consistent with those in McLean's (1988) study, in that constant-component performances for the whole component do not show behavioral contrast in response allocation. That is, the value for n with whole-component performances here and in McLean (1988) is 0.

Local Contrast

Absolute response rates for individual subintervals are given in the Appendix. Figure 2 plots absolute response rates in subintervals of components for those conditions in which the concurrent schedule arranged in Component 2 was different from that in Component 1. Rates in the constant component are given by unfilled circles. For the left key, where the reinforcer manipulation for Component 2 occurred, there was clear local contrast in most cases. In the constant component, all birds showed positive local contrast in Condition 2 (R_{L2} = 5 per hour) and negative local contrast in Condition 4 (R_{L2} = 40 per hour). Three of the birds showed the exact reverse patterns in the varied component.

No reinforcer rate change was scheduled for the right key over conditions in either component. Yet there are reasonably clear local contrast effects on the right key as well as on the left. In all cases, these changes in right-key responding over subintervals were the reverse of the changes that occurred on the left key during the same component, and were usually quite similar to the left-key performances in the opposite component. For example, Bird A1's left-key responding showed negative local contrast during the varied component in Conditions 2 and 3 (R_{L2} = 5 and 10 per hour, respectively) and positive local contrast in Condition 4 (R_{L2} = 40 per hour). Right-key responding during the constant component showed the same pattern.

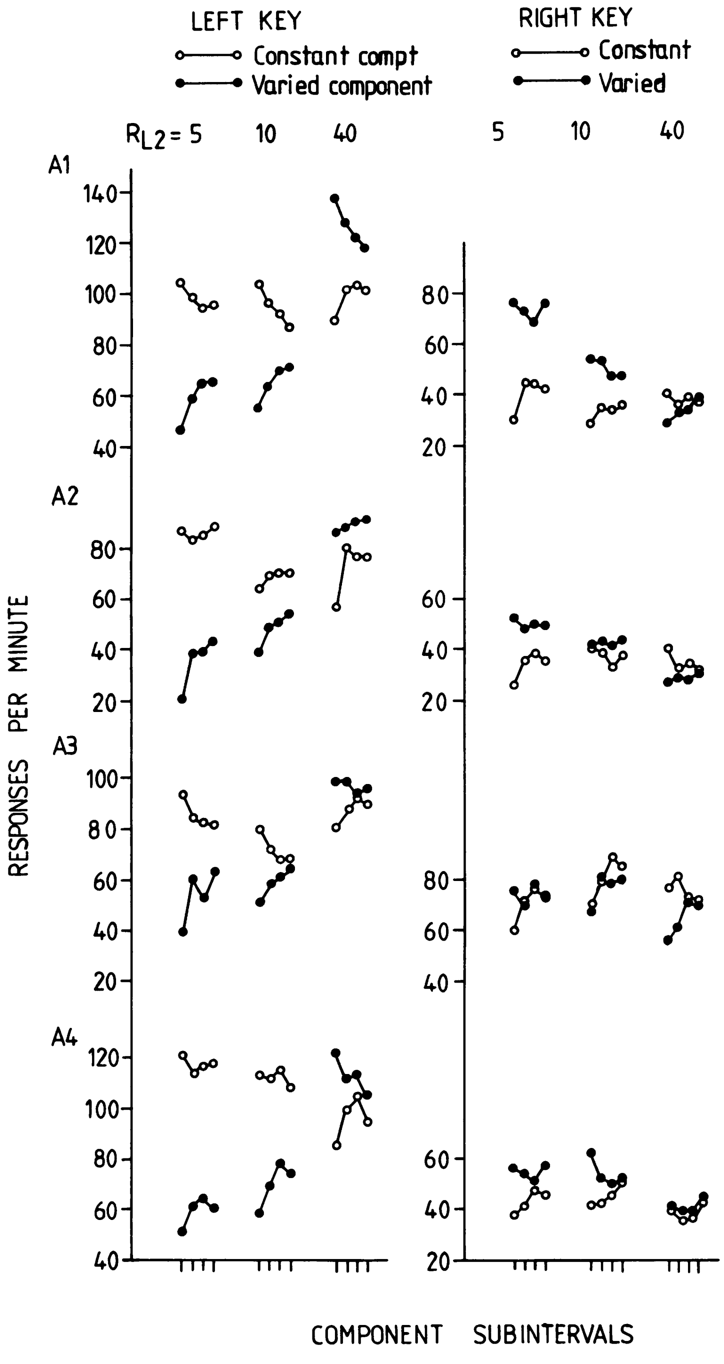

Fig. 2. Responses per minute during successive subintervals of Components 1 (unfilled circles) and 2 (filled circles), for Conditions 2, 3 and 4. The left side of the figure gives left-key performances in Components 1 and 2, and the right side gives right-key performances.

In the case of the varied component, these changes in right-key responding may arise from changes in the value of the competing left-key schedule, but performances in the constant component, where no reinforcer change occurred over conditions, indicate an influence of reinforcement in the alternated component (i.e., successive interaction). As mentioned ear-

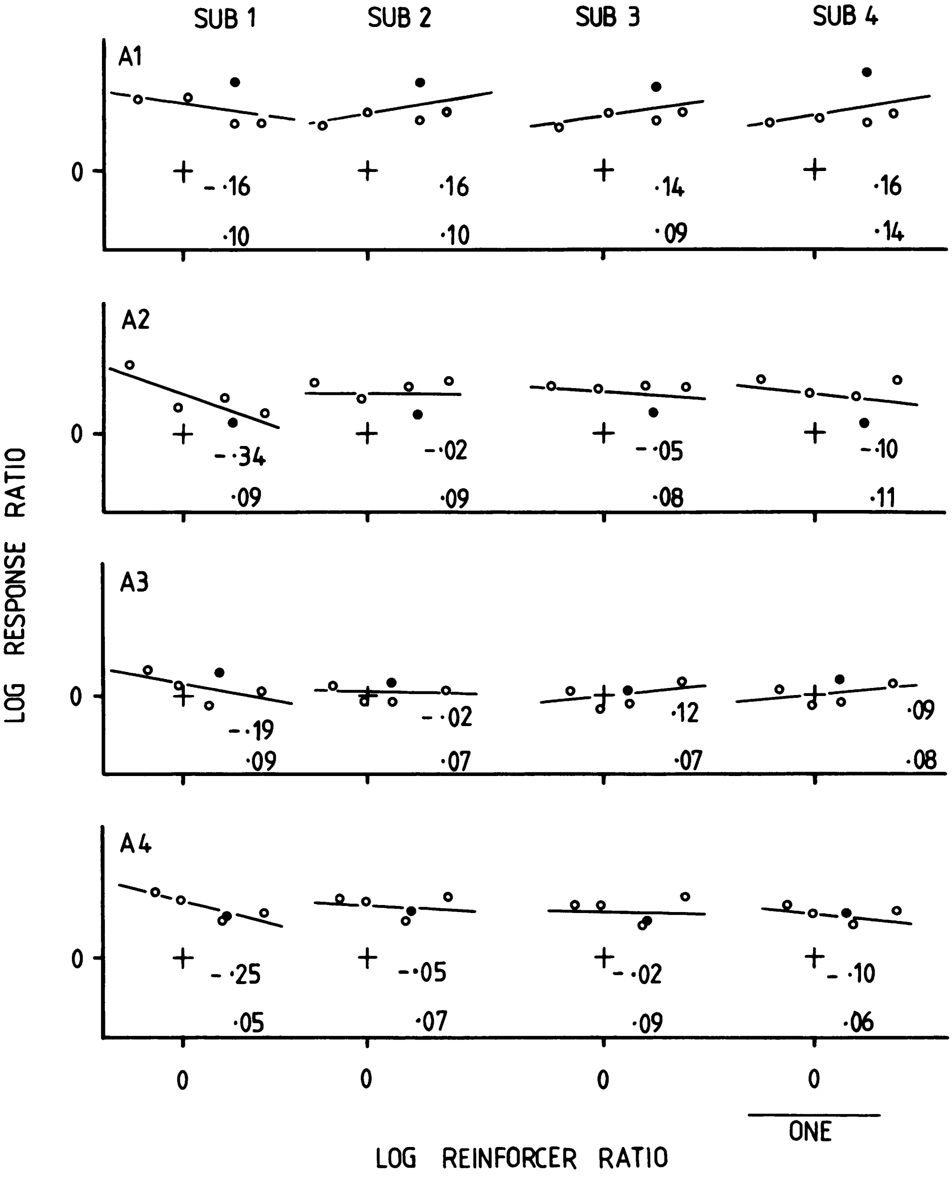

Fig. 3. Log ratios of response rates (left/right) in subintervals of Component 1 (constant component), plotted as a function of log ratios of reinforcers obtained during Component 2 (varied component). For each subject and each subinterval, the slope of a fitted least squares regression line is given near the origin (cross). Beneath the slope is given the standard error of estimate. The filled circle gives data from Condition 1.

lier, behavior-allocation data may be a more appropriate measure for studying contrast, and Figure 3 gives behavior-allocation data for the constant component, plotted as a function of log reinforcer ratios in the varied component (i.e., treated in the same way as whole-component performances were in Figure 1). Separate functions are given for each of the four subintervals. In the first subinterval, negative slopes (i.e., negative values for n in Equation 2) were found for all birds, and ranged between -0.16 and -0.34. In Subintervals 2, 3 and 4, slopes were greater and usually closer to 0. The consistent inverse relationship between first-subinterval behavior allocation and reinforcer ratios in the alternate component quantify local contrast and are in marked contrast to whole-component performances here (Figure 1) and in McLean (1988).

The contribution of local contrast to behav-

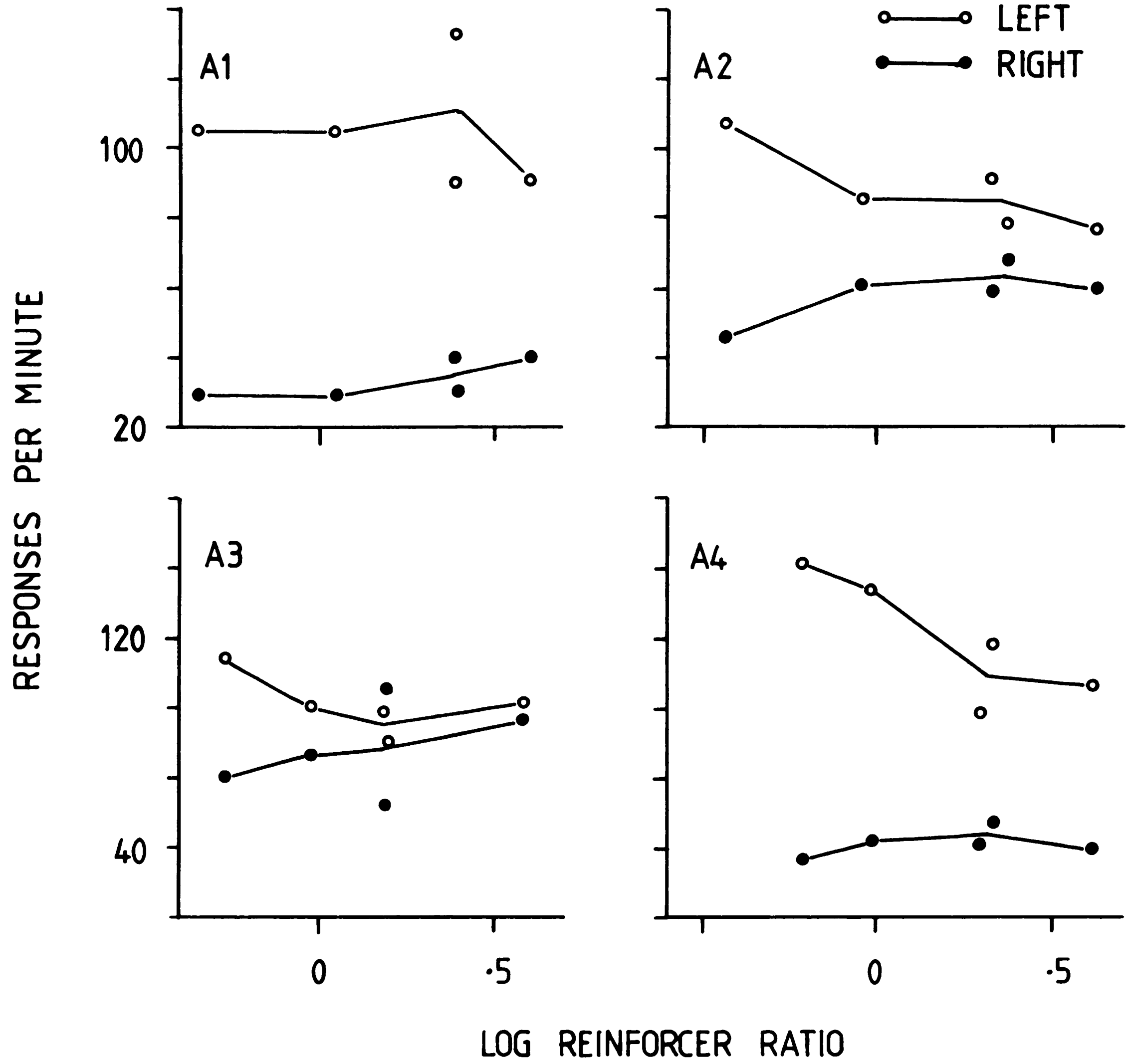

Fig. 4. Responses per minute during the first subinterval of Component 1 (constant component) on the left key (unfilled circles) and right key (filled circles), plotted as a function of log ratios of reinforcers obtained during Component 2. Data from Conditions 1 and 5, which employed identical schedules, were averaged before the solid line was drawn.

ioral contrast during the first subinterval is shown in Figure 4. Figure 4 gives absolute response rates in the first subinterval of Component 1 plotted as a function of logarithms of Component 2 reinforcer ratios (the absolute reinforcer rate, R_{L2}, was correlated with reinforcer ratio because of the constant R_{R2}). Performances on the left key are negatively related to Component 2 reinforcer ratios (i.e., to R_{L2}; behavioral contrast). More interesting are the response-rate changes on the right key, where the reverse relation is apparent. With some uncertainty in the case of Bird A4, right-key responding in Component 1 was positively related to R_{L2}. That is, with two responses available in the constant component, subjects showed contrast for one response (left key) and induction for the other response (right key).

Concurrent Performances over Subintervals

Figure 3 showed that the value for n in Equation 2 was negative in the first subinterval of components and approached or exceeded

0 as components progressed. Equation 2 makes predictions about changes in concurrent matching performances (see left panels of Figure 1) over subintervals, if n changes in this way. Writing Equation 2 for Component 2 performances gives

$$\log_{10}\left(\frac{P_{L2}}{P_{R2}}\right) = a \log_{10}\left(\frac{R_{L2}}{R_{R2}}\right) + n\left[\log_{10}\left(\frac{R_{L1}}{R_{R1}}\right) - \log_{10}\left(\frac{R_{L2}}{R_{R2}}\right)\right] + \log_{10}c,$$

and rearranging terms, gives,

$$\log_{10}\left(\frac{P_{L2}}{P_{R2}}\right) = (a - n)\log_{10}\left(\frac{R_{L2}}{R_{R2}}\right) + n \log_{10}\left(\frac{R_{L1}}{R_{R1}}\right) + \log_{10}c. \quad (3)$$

It can be seen that for negative values of n in the first subinterval, the predicted slope of the concurrent matching line in Component 2, $a - n$, is greater than concurrent sensitivity, a. For positive values of n (i.e., in later subintervals), the predicted slope is less than sensitivity a. The intercept, with R_{L1}/R_{R1} constant over conditions, is $n \log(R_{L1}/R_{R1}) + \log(c)$. With constant concurrent sensitivity over subintervals, Equation 3 therefore predicts decreases in the slope of the concurrent matching line over subintervals, because of changes in the extent of successive interaction with the alternate-component reinforcer ratio (n). Similarly, with c constant over subintervals, Equation 3 predicts small increases in preference for the left key in Component 2 as n increases.

Figure 5 gives the concurrent performances in Component 2 separately for each subinterval. For all birds, the greatest slope was found in first-subinterval performances, and slopes decreased systematically over the remaining subintervals of components. Fitted slopes were not consistently different from $a - n$ in any subinterval (using a estimates from Figure 1 and n estimates for subintervals from Figure 3). Slopes and intercepts of fitted regression lines for the varied component were therefore affected by successive interaction of reinforcer ratios in components in the way predicted by Equation 3.

DISCUSSION

Results from this study are consistent with those of earlier work using multiple-concurrent schedules in finding invariant response ratios in one component when the reinforcer ratio (and absolute rate) is varied in an alternated component. When behavior allocation was studied using response rates averaged over subintervals, behavior allocation in a constant multiple-concurrent schedule component was unaffected by reinforcement changes in a second component. Thus, these results are consistent with McLean and White's (1983) and McLean's (1988) conclusion of successive independence of whole-component performances.

However, these results do not support successive independence for performances in subintervals of components, which showed clear evidence of direct interaction among reinforcer ratios from the two components in determining behavior allocation. The results for individual subintervals are summarized in Figure 6. In the constant component, interaction (i.e., successive dependence) was revealed in an inverse relation between first-subinterval response ratios and varied-component reinforcer ratios. Thus, slopes of these functions were negative for first-subinterval data. Over subintervals the interaction weakened as components progressed (shown in strongly increasing slopes), sometimes reverting from an inverse relationship to a positive one. Consequently, whole-component performances (Figure 1) showed no positive or negative slopes consistently across subjects. In the varied component, functions relating first-subinterval response ratios to same-component reinforcer ratios were clearly steeper than slopes for performances in the whole component. These functions decreased strongly and systematically as components progressed.

Nevin et al. (1978) also found an inverse relationship between response allocation in one component and reinforcer ratios in an alternated component. Their study used discrete-trials responding in components, rather than free-operant responses, and in showing this interaction produced results in clear contrast to the whole-component performances here and in McLean (1988) but quite similar to first-subinterval performances in this study. In one respect, at least, it is not surprising that behavior in first subintervals of the free-operant procedure shows similar effects to discrete-tri-

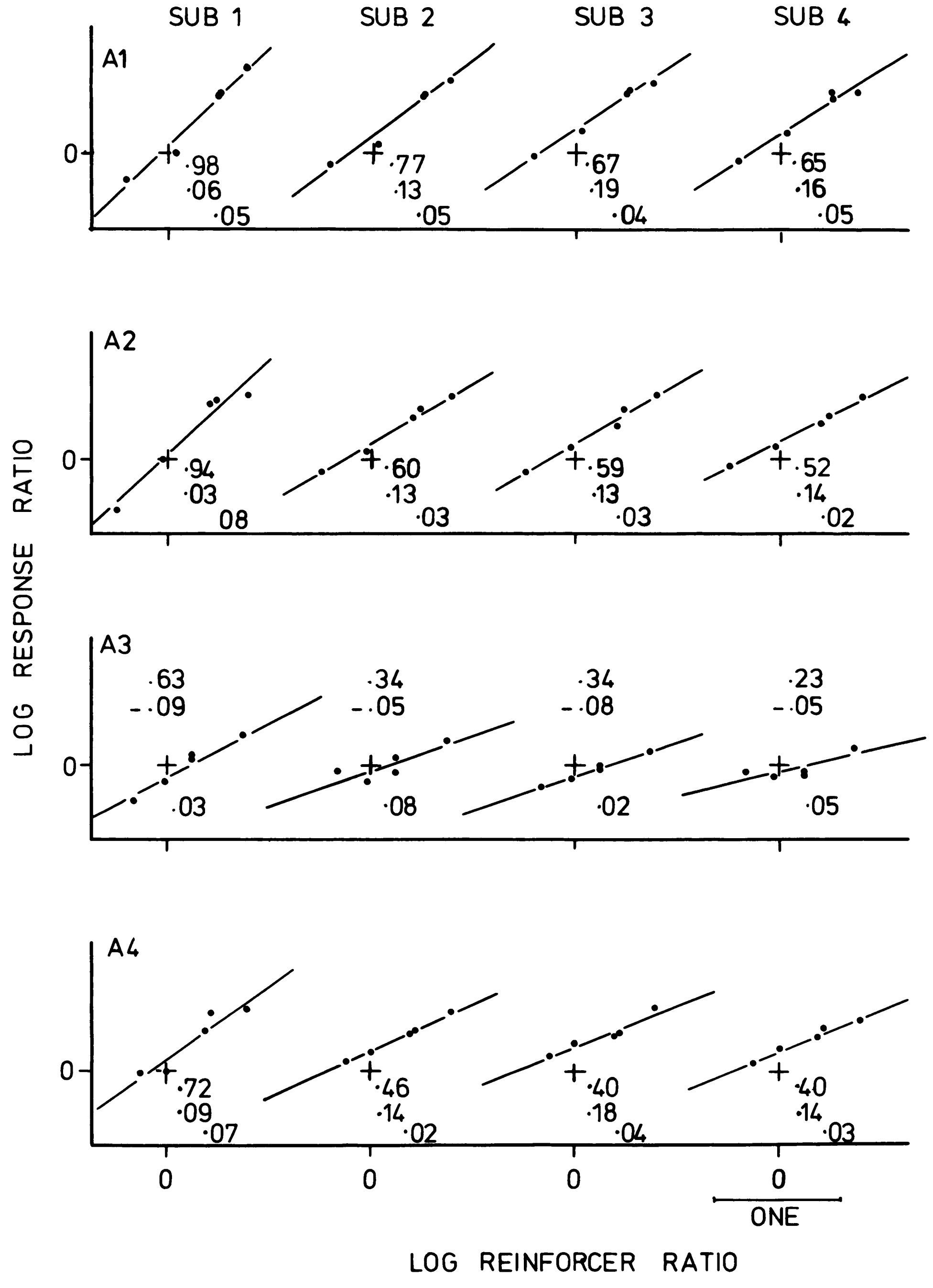

Fig. 5. Log ratios of response rates (left/right) in subintervals of Component 2 (varied component), plotted as a function of log ratios of reinforcers obtained during Component 2. For each subject and each subinterval, the slope of a fitted least squares regression line is given. Beneath the slope is given the intercept of the line, and at the bottom is given the standard error of estimate.

als responding, because in both cases the behavior studied is that which occurs within a short time after the onset of a discriminative stimulus. However, Nevin (1988) has noted a number of other differences between behavior generated in the two procedures, and it is not yet clear to what extent conclusions can be generalized from one to the other.

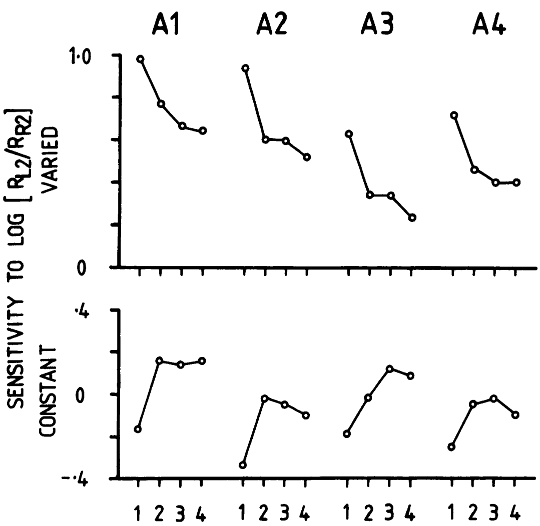

Fig. 6. Slopes of regression lines fitted to Component 1 log response ratios (lower panel) and Component 2 log response ratios (upper panel) versus changes in Component 2 log reinforcer ratios. For each bird, slopes are plotted over successive subintervals of components.

Analyzed using Equation 1, performances over subintervals of the varied component in this experiment would have to be interpreted as showing changes in concurrent sensitivity, *a*, as a function of time since the onset of exposure to a concurrent schedule. However, concurrent sensitivity could not account for the response-ratio changes over conditions in first subintervals of the other component, in which the reinforcer ratio was constant over conditions. Moreover, possible changes in sensitivity to reinforcement conditions in the same component cannot account for the slope changes over subintervals during Component 1, and consequently Equation 1 is inadequate to characterize the results described here.

A major advantage of the present analysis (Equation 2 or 3) is that the shifts in concurrent performance, observed over subintervals in both of the components, are always accounted for in terms of changes in the influence of the successive context of the component. Slopes of matching lines in the varied component are equal to $a - n$ in Equation 3, and high slopes are predicted for first subintervals because n is negative at that time (slopes are then a plus the absolute value of n). Decreases in slope over subintervals are predicted because the effect of alternate-component reinforcer ratios decreases as that component becomes more distant in time (i.e., n changes from negative toward positive values as subintervals pass). Thus, Equation 3 accounts for the changes in behavior allocation in both components in terms of one process—the reduction of interaction among components as a function of time since the previous component.

In this research, response allocation (rather than response rate) was used to study contrast because it is almost certainly unaffected by possible reallocation of "extraneous" reinforcers, and interaction found with response ratios is therefore incompatible with the reallocation theory of contrast. Thus, whereas behavioral contrast in whole-component performances may yet be mediated by reallocation of extraneous reinforcement (because successive independence was confirmed again for whole-component performances), it seems clear that local contrast represents a direct interaction among components. Reallocation of extraneous reinforcement cannot be invoked as a reasonable account of contrast in response ratios because response ratios have been shown to be unaffected by changes in a third, concurrently accessible contingency, and are surely also independent of concurrently available extraneous reinforcement. In view of the failure to affect response allocation using an explicitly programmed alternative, the local contrast in response ratios found here is not explicable in terms of reallocated extraneous reinforcers.

In addition to this advantage to studying behavior allocation in the context of contrast, data from the constant component suggest a further advantage as well. Figure 4 showed that when reinforcer rate was varied on one key in Component 2, response rate in Component 1 (first subinterval) showed contrast on one key but showed induction for 3 of the 4 birds on the other key. No existing account of behavioral contrast in multiple schedules predicts that alternative responses in a constant component will show opposite relationships to reinforcement rate in a successively alternated component. These diverse changes in absolute response rate in the constant component must be described in terms of two relationships, whereas contrast expressed in terms of behavior allocation represents only a single relationship. Moreover, contrast in behavior allocation could obtain if absolute rate changes were observed with both or only one of the response alternatives during the constant component. Equation 2 therefore seems likely to describe a wider variety of constant-component performances than an absolute-rate formulation could do.

Equation 2 is similar to an equation proposed by McLean and White (1983). In their equation,

$$\log_{10}\left(\frac{P_{L1}}{P_{R1}}\right) = a \log_{10}\left(\frac{R_{L1}}{R_{R1}}\right) + n \log_{10}\left(\frac{R_{L2}}{R_{R2}}\right) + \log_{10}c, \quad (4)$$

where a quantifies sensitivity of behavior ratios to reinforcer ratios in the same component, and n quantifies sensitivity of behavior ratios in a component to reinforcer ratios in another component. This version has, however, the undesirable feature that the term that describes the effect of reinforcement in an alternate component (i.e., the source of contrast in Component 1 behavior) is 0 if the reinforcer ratio R_{L2}/R_{R2} is 1.0. That is, for any value for n, Component 2 reinforcement is, in Equation 4, predicted to influence Component 1 response allocation only if it is different from 1.0. Equation 2 is derived making the more reasonable assumption that Component 2 reinforcement will influence Component 1 behavior if R_{L2}/R_{R2} is different from R_{L1}/R_{R1}—even if R_{L2}/R_{R2} is 1.0. That is, Equation 2 says that the source of contrast (for negative values of n) or induction (for positive values) in Component 1 is the extent to which Component 1 and Component 2 reinforcer ratios are different from one another. The relationship between the two reinforcer ratios is captured in Equation 2 as follows:

$$\log_{10}\left(\frac{P_{L1}}{P_{R1}}\right) = a \log_{10}\left(\frac{R_{L1}}{R_{R1}}\right) + n \log_{10}\left(\frac{R_{L2}/R_{R2}}{R_{L1}/R_{R1}}\right) + \log_{10}c.$$

From which, rearranging terms, yields Equation 2:

$$\log_{10}\left(\frac{P_{L1}}{P_{R1}}\right) = a \log_{10}\left(\frac{R_{L1}}{R_{R1}}\right) + n\left[\log_{10}\left(\frac{R_{L2}}{R_{R2}}\right) - \log_{10}\left(\frac{R_{L1}}{R_{R1}}\right)\right] + \log_{10}c.$$

Of course, for the conditions arranged in the present experiment the term $\log_{10}(R_{L1}/R_{R1})$ is a constant, so the analysis shown for Component 1 performances in Figures 1 and 3 are plots of the relation

$$\log_{10}\left(\frac{P_{L1}}{P_{R1}}\right) = n \log_{10}\left(\frac{R_{L2}}{R_{R2}}\right) + \log_{10}b,$$

where $\log_{10}b = (a - n)\log_{10}(R_{L1}/R_{R1}) + \log_{10}c$. Thus, the term n has exactly the same interpretation here as in McLean and White (1983) and McLean (1988), where Equation 4 was used—the sensitivity of behavior ratios in one component to reinforcer ratios in a temporally distant component.

What sort of experimental variables might affect the value of n? McLean and White's (1983) conclusion of successive independence ($n = 0$) so far appears to have considerable generality, at least with whole-component performances. However, one condition under which nonzero values may obtain is when the stimuli signaling the two components are difficult to discriminate. Indeed, reanalysis of data from studies of signal detection performance in pigeons, which typically use marginally discriminable stimuli, confirms that estimates for n are positive in these procedures. Data from Davison and McCarthy's (1980) study, in which reinforcers were scheduled for "correct" and "error" responses in two components signaled by different stimulus durations, were analyzed using Equation 2. The fits of Equation 2 were quite good, with an average of 96% of the variance in log response ratios accounted for by predictions. Values of a (concurrent sensitivity) were lower than the reported values for a_r (sensitivity to reinforcement in their analysis), and values of n were positive for each of 6 birds. Similarly, manipulation of other variables might bring about negative values of n. Some writers have suggested that absolute-rate contrast arises from a number of different processes, and it is possible some of these are related to direct interaction and others relate to reallocation. For example, Williams (1988, 1990) has suggested that some experimental variables affect the extent of contrast due to the following reinforcement schedule, whereas others affect contrast due to the preceding schedule. Possible determinants of n are therefore those variables known to affect absolute-rate behavioral contrast, including component duration (McSweeney, 1982; Williams, 1979) and the extent of training given in conditions with different component reinforcer rates.

Equation 2 can readily be extended to account for absolute-rate local contrast effects in regular multiple (rather than multiple-concurrent) schedules. For multiple schedules, extraneous reinforcement, R_0, is substituted for right-key reinforcers in Components 1 and 2:

$$\log_{10}\left(\frac{P_1}{P_{01}}\right) = (a - n)\log_{10}\left(\frac{R_1}{R_{01}}\right) + n\log_{10}\left(\frac{R_2}{R_{02}}\right) + \log_{10}c,$$

where P_1 is response rate in multiple-schedule Component 1, P_{01} is behavior other than key pecking in Component 1, R_1 and R_{01} are reinforcers for key pecking and other behavior, respectively, and other terms are defined as before. Local contrast is then predicted in the allocation of Component 1 behavior between key pecking and other activities. Now if $P_1 + P_{01} = k$, and k is more or less invariant with respect to reinforcement rate in Component 2, then changes in behavior allocation in Component 1 will produce changes in absolute frequency of responding, P_1. The same change in behavior allocation will also produce an opposite change in the frequencies of activities constituting P_{01}, as the present results suggest (Figure 4). A similar analysis was advanced by McLean and White (1983) for contrast in whole-component response rate.

There is at least one clear difficulty with the formulation given in Equation 2, however, that arises if extinction is in effect for any response. That is, if either left- or right-key reinforcer rate is 0 in either of the two components, then Equation 2 makes the unlikely prediction that log response ratios are infinite in *both* components. Consequently, extinction has to be accepted as a boundary condition for the present analysis, which is therefore silent about differences in contrast observed in the many procedures that have used extinction. Notwithstanding this difficulty, Equation 2 has several advantages over existing formulations for contrast, which are usually given in terms of absolute response and reinforcer rate. First, it identifies a form of contrast that cannot reasonably be explained in terms of changes in a hypothetical contingency (extraneous reinforcement). Although the existence of that contingency is still assumed in extrapolating from multiple-concurrent to regular multiple schedules, contrast is not explained in terms of changes in extraneous reinforcement. Second, Equation 2 can account for contrast in absolute response rates, as well as that in response allocation, given the further assumption that $P_1 + P_{01} = k$, which is approximately constant. The case for a strictly constant k has been argued elsewhere (see Herrnstein, 1970, 1974; McLean & White, 1983). Third, the free parameter n in Equation 2 quantifies the extent of component interaction and does so for performances from both components. Finally, Equation 2 can deal simply with a variety of changes in absolute rate on different response alternatives during a component.

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APPENDIX

Responses per minute in subintervals of Components 1 (constant) and 2 (varied) on left and right keys.

Condition	Component	Left key				Right key			
		Sub 1	Sub 2	Sub 3	Sub 4	Sub 1	Sub 2	Sub 3	Sub 4
Bird A1									
1	1	131.84	143.41	131.21	145.56	30.31	31.59	31.07	26.61
	2	116.99	121.50	124.72	113.63	39.77	40.81	38.91	39.95
2	1	105.12	99.32	95.07	96.38	29.97	45.58	44.44	42.51
	2	46.69	59.41	65.16	65.22	75.80	72.71	68.25	75.94
3	1	104.45	97.22	91.55	87.48	29.09	35.07	34.38	35.87
	2	54.65	64.21	70.41	70.51	53.93	52.80	46.63	47.63
4	1	90.48	102.18	103.43	100.79	39.86	36.25	38.89	38.83
	2	137.54	128.04	122.57	118.54	28.89	33.43	33.50	38.61
5	1	90.63	96.76	92.23	95.38	40.33	40.26	39.74	41.92
	2	93.95	94.68	99.37	96.38	33.13	32.82	32.72	31.09
Bird A2									
1	1	58.26	67.27	66.37	61.93	48.38	48.14	46.23	51.02
	2	83.34	81.57	85.14	80.60	28.82	33.50	33.95	36.03
2	1	87.44	84.04	86.03	86.69	26.62	35.42	38.30	35.45
	2	21.33	38.64	39.87	44.28	52.19	48.15	49.85	49.27
3	1	64.75	70.02	73.31	73.58	40.53	38.70	33.74	36.83
	2	40.32	49.39	51.44	55.27	40.93	42.78	40.80	44.46
4	1	57.24	80.57	77.49	77.35	40.49	32.15	34.36	31.53
	2	86.39	89.02	91.34	91.87	27.09	28.90	28.19	30.04
5	1	72.63	85.29	87.59	82.30	39.46	38.18	37.90	43.78
	2	71.33	76.69	78.73	79.56	25.92	35.54	41.98	40.42
Bird A3									
1	1	79.12	82.80	78.95	82.17	52.68	64.36	69.90	62.35
	2	71.92	79.96	73.45	73.24	59.80	68.39	73.24	77.19
2	1	93.71	84.79	82.84	81.90	59.82	70.83	75.72	72.67
	2	39.85	61.45	53.94	63.49	75.35	69.37	78.13	71.72
3	1	80.53	71.93	67.82	69.65	66.65	79.04	88.09	85.09
	2	52.14	58.46	61.68	65.26	70.70	81.16	78.36	79.86
4	1	81.28	88.17	92.92	89.70	75.95	81.28	73.73	72.83
	2	98.70	99.16	94.44	96.25	56.36	61.40	71.11	69.62
5	1	70.19	71.85	74.91	75.36	85.38	82.09	88.09	85.87
	2	78.90	73.23	79.39	75.24	70.22	86.17	86.34	89.70
Bird A4									
1	1	98.25	105.08	92.36	100.47	47.12	47.36	48.95	56.19
	2	106.14	99.51	99.92	103.64	38.78	51.66	51.98	50.14
2	1	121.54	114.71	117.10	118.25	37.34	41.06	46.47	45.71
	2	51.88	62.50	64.74	65.10	56.23	53.58	50.82	56.78
3	1	113.90	112.20	115.14	108.45	40.79	42.21	45.12	50.43
	2	59.23	69.91	79.55	75.24	62.04	52.16	50.14	52.22
4	1	86.05	99.77	104.77	95.41	39.21	34.92	35.82	41.94
	2	121.52	112.22	114.38	106.97	40.74	39.64	38.68	45.32
5	1	78.55	87.93	84.26	83.77	41.70	45.92	49.28	47.69
	2	97.25	97.14	95.45	95.27	47.05	52.42	53.91	56.57