

UNDERMATCHING AND CONTRAST WITHIN COMPONENTS OF MULTIPLE SCHEDULES

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Six multiple variable-interval schedules each comprised one variable-interval sixty second component and an alternated component which was varied. Four pigeons' responses were recorded in five successive subintervals of each component. Response rate changes across subintervals revealed instances of local contrast and small local induction effects in the changed component. In the constant component, smaller local contrast and larger local induction effects obtained. Accordingly, the magnitude of behavioral contrast, defined as an inverse relation between response rate in the constant component and reinforcement rate in the changed component, did not change reliably across subintervals of the constant component. Ratios of response rates in initial subintervals were highly sensitive to reinforcement ratios. Sensitivity decreased sharply over the first two-fifths of the components and remained constant for the remainder. The results demonstrated that changes in multiple schedule sensitivity are a function of time since the alternation of successive components.

Key words: undermatching, behavioral contrast, local contrast, component subintervals, multiple variable-interval schedules, key peck, pigeons

In a multiple variable-interval variable-interval (mult VI VI) schedule, two component VI schedules alternate in succession, usually at a constant rate. The distribution of responses between components of mult VI VI schedules varies as a function of the distribution of reinforcements between components, according to what has become known as the generalized matching relation (Baum, 1974):

$$\log (P_1/P_2) = a \log (R_1/R_2) + \log c. \quad (1)$$

In Equation 1, P represents response rate, R represents reinforcement rate and the subscripts identify the components in which they occur. Two free parameters, a and c , are estimated empirically using a wide range of reinforcement ratios, and quantify respectively *sensitivity* of response ratios to reinforcement ratios and *bias* towards one or other component. Where response and reinforcement ratios covary perfectly, a has a value of 1.0 (i.e.,

"matching" of response to reinforcement ratios). Matching is approximated in concurrent variable-interval schedules, where components are arranged simultaneously rather than successively (Baum, 1979; de Villiers, 1977; Myers & Myers, 1977). In multiple schedules, response ratios undermatch reinforcement ratios, and typical estimates of a are between .3 and .5 (Davison & Ferguson, 1978; Lander & Irwin, 1968). Unless different response topographies are required in the two components, response bias is usually small and c is thus close to unity. In situations where c deviates from unity however, Equation 1 enables independent assessment of sensitivity and response bias, whereas previous formulations (Herrnstein, 1961, 1970) have confounded them (Baum, 1974).

A second relation frequently observed in multiple schedules is behavioral contrast (Reynolds, 1961). Behavioral contrast is an inverse relation between response rate in one component and reinforcement rate in the other. Thus, if the reinforcement rate in one component remains constant and that in the other is decreased, positive behavioral contrast appears as an increase in response rate in the constant component. Behavioral contrast could contribute to multiple schedule sensitivity by increasing response ratios, although in princi-

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ple ratios and absolute response rates are independent.

Multiple schedule performance may vary as a function of the temporal separation of components. Indeed this temporal constraint is one of the major procedural distinctions between multiple and concurrent schedules. In concurrent schedules the components are simultaneously available and the subject switches fairly rapidly between them (Killeen, 1972). In a multiple schedule, switches between components are arranged by the experimenter and typically occur after relatively long intervals. Performance in concurrent schedules is therefore sampled at points soon after alternation between components, whereas in multiple schedules performance is averaged over much longer times since component alternation.

Nevin and Shettleworth (1966) recorded response rates in successive subintervals of multiple schedule components, thus sampling response rates at different temporal distances from component alternation. When component schedules arranged reinforcement at different rates ($R_1/R_2 \neq 1.0$), response rates in higher value components were initially high and decreased to an asymptotic level towards the end of the component. In low valued components, response rates were initially low and increased to an asymptote. These effects have been called positive and negative local contrast respectively (Malone & Staddon, 1973) and have also been reported by Arnett (1973), Malone (1976), Menlove (1975), and Rachlin (1973) among others. Reverse effects (local induction) have also been reported. Buck, Rothstein and Williams (1975) found negative local contrast in low valued components and negative local induction in high valued components.

Local contrast is usually transient, appearing at an intermediate stage in discrimination training. However, Malone and Staddon (1973) found that local contrast can persist under some conditions, and it is therefore possible that local contrast may contribute to steady-state multiple schedule contrast and sensitivity. First, if positive and negative local contrast appear reliably in a constant component, behavioral contrast may decrease across subintervals. Second, larger differences between absolute response rates soon after component alternation will reveal more extreme ratios of response rates early in components. That is, sensitivity of response ratios to reinforcement

ratios may be higher soon after component alternation than later in the component. In the present study, we examined changes in behavioral contrast and response ratio sensitivity (undermatching) within components of a wide range of multiple schedules of reinforcement.

METHOD

Subjects

Four homing pigeons, each with brief experimental histories in multiple schedules, were maintained at $80 \pm 5\%$ of their free-feeding weights. Water and grit were always available in home cages, and supplementary feeding ensured maintenance of prescribed weights.

Apparatus

A light-proof, sound-attenuating chamber with internal dimensions of 35 by 32.5 by 32 cm contained an interface panel. All interior surfaces were painted matte black except a one-way mirror in the door. A 2.5-cm diameter response key was located 22.5 cm above the floor and central in the interface panel. The key could be operated by a minimum force of .2 N and was illuminated with either green light (S1) or red light (S2) by a stimulus projector fitted with Kodak Wratten filters 55 and 70. The stimulus projector was powered by an independent 24-V supply. A feeder aperture was located 10.5 cm below the key. Reinforcement was 3-sec access to wheat during which the feeder was illuminated with white light. General illumination during experimental sessions was provided by a dim houselight on the wall adjacent to the interface panel. A ventilation fan at the rear of the chamber helped mask extraneous sounds. Standard electromechanical programming apparatus, located in an adjacent room, scheduled and recorded all experimental events.

Procedure

Following one hour of preliminary training during which key pecking was reestablished and each peck was reinforced, each bird was exposed to a series of six multiple schedule conditions. Throughout all conditions, 90-sec presentations of S1 alternated directly with 90-sec presentations of S2. Responses always produced .05-sec offset of the keylight and reinforcers were always accompanied by 3-sec keylight offset. In the first five conditions, S1 sig-

naled a VI 60-sec component. In each of these conditions, the component associated with S2 had one of five values from VI 15-sec through VI 240-sec. Finally, all birds were exposed to mult VI 240-sec VI 60-sec, in which S1 signaled VI 240-sec reinforcement. The VI schedules comprised 12 randomized intervals from the Fleshler and Hoffman (1962) progression. Orders of conditions were different for each bird. Table 1 gives the schedule values in each condition and the order of conditions for each bird. Session durations were 60 min except where scheduled reinforcement rates were high, and sessions were shortened to 21 or 30 min to maintain prescribed body weights.

For each bird, daily sessions were continued within a condition for at least 14 sessions and until a stability criterion had been met. The criterion was that for five consecutive sessions the bird's relative response rate— $P_1/(P_1 + P_2)$ or $P_2/(P_1 + P_2)$, whichever was the smaller—fell within 5% of the mean relative response rate for the five sessions. This criterion allowed very little daily fluctuation with extreme relative response rates, and once was relaxed to five of six consecutive sessions when the performance of P-26 had not stabilized after prolonged training in mult VI 240-sec VI 60-sec. The number of days training in each multiple schedule are given in Table 1.

Responses were recorded separately in each of five 18-sec subintervals of the 90-sec components. Reinforcers were recorded as totals for each component. The constant-probability basis for the VI generation allowed the assumption that for any component, reinforcement was equiprobable in all subintervals.

RESULTS

The response and reinforcement rate measures used in all subsequent analyses were from the five sessions in which the stability criterion was satisfied. Response rates were corrected for reinforcement time.

Figure 1 shows, for each multiple-schedule condition, response rates in each component plotted as a function of time since component alternation. In each case, rates in subintervals of S1 components are connected. Moderate positive local contrast appeared in 11 of 20 possible instances (differential multiple schedules) in that response rates were higher at the beginning of the richer component. Rather stronger

Table 1

Multiple schedule conditions in order of exposure for each bird, and number of sessions training in each. Where session durations were not 60 min, actual durations are given in parentheses.

Bird	Schedules (sec)		Sessions
	S1	S2	
P-12	VI 60	VI 15 (30 min)	23
	VI 60	VI 120	14
	VI 60	VI 30	16
	VI 60	VI 60	26
	VI 60	VI 240	14
	VI 240	VI 60	43
P-17	VI 60	VI 60	23
	VI 60	VI 120	38
	VI 60	VI 240	29
	VI 60	VI 30	30
	VI 60	VI 15 (21 min)	14
	VI 240	VI 60	14
P-24	VI 60	VI 240	22
	VI 60	VI 60	19
	VI 60	VI 120	22
	VI 60	VI 15 (21 min)	18
	VI 60	VI 30	15
	VI 240	VI 60	29
P-26	VI 60	VI 15 (21 min)	21
	VI 60	VI 240	22
	VI 60	VI 30 (30 min)	21
	VI 60	VI 120	16
	VI 60	VI 60	14
	VI 240	VI 60	18

negative local contrast appeared in 14 instances, indicated by an increase in rate within leaner components. Both effects appeared reliably for all birds only in mult VI 60-sec VI 240-sec and mult VI 240-sec VI 60-sec conditions. In the five schedules where S1 signaled VI 60-sec components, positive and negative local contrast were greater in the changed component than in the constant component for P-12, P-17, and P-24.

Figure 2 shows absolute response rates in both components plotted as a function of logarithm of reinforcement rate ratios. Ratios are rates in S1 divided by rates in S2. Extreme left panels show overall response rates, and other panels show rates in individual subintervals. Rates in the constant component are represented by unfilled circles connected by straight lines. Filled circles represent rates in the changed component. Data from mult VI 240-sec VI 60-sec, where the VI 60-sec component was signaled by S2 rather than S1, are represented by filled (VI 240-sec) and unfilled squares and are plotted against $\log(R_2/R_1)$.

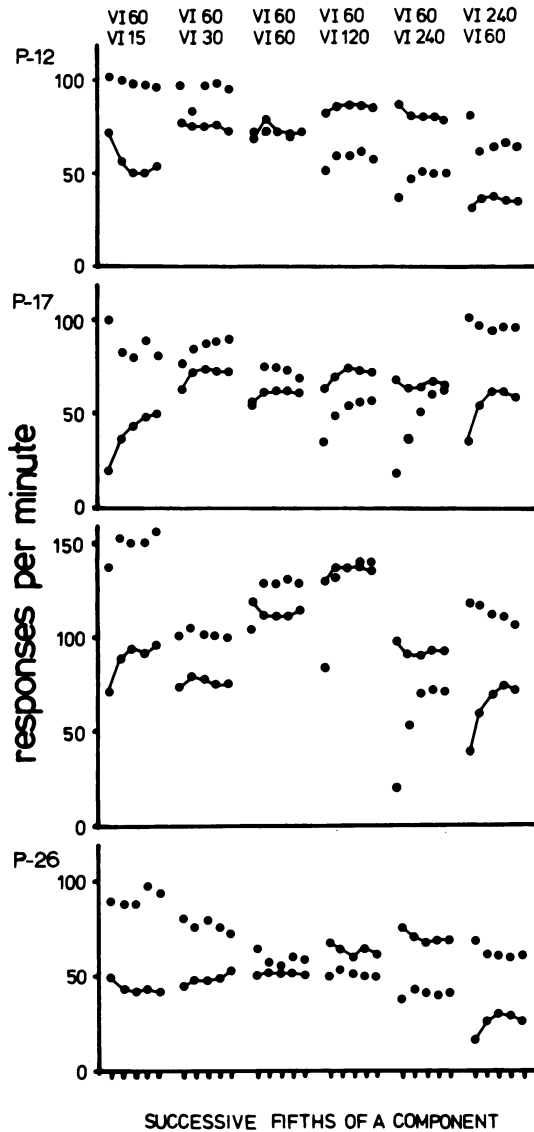


Fig. 1. Absolute response rates in successive subintervals of components of each multiple schedule. Rates in subintervals of S1 are connected.

Figure 2 shows behavioral contrast in the performances of all birds in that overall response rate (left panels) in the constant component increased as a function of reinforcement ratios. That is, response rate in S1 varied inversely with reinforcement rate in S2. The magnitude of contrast is indexed by the rate of change of response rate in the constant component. Comparison of plots for successive subintervals shows no consistent change in behavioral contrast as a function of time since component alternation, despite the instances of

local contrast in Figure 1. For all birds, the relation between absolute response rate and reinforcement ratios was more pronounced in the changed component than in the constant component. Moreover, this relation was strongest and most systematic at the beginning of the changed component, and decreased in later subintervals; consistent with the strong negative local contrast effects in S2 (Figure 1).

Figure 3 shows logarithms of response rate ratios plotted as a function of logarithms of reinforcement rate ratios. The equations of least squares regression lines (solid lines) and standard errors of estimate, are given in each panel. Standard errors were used as a measure of how well the regression lines fitted the data because they are independent of the slope of the regression line. Slopes indicated strong undermatching and were typical of performance in multiple variable-interval schedules: values of a ranged from .34 to .53. In each case, standard errors were less than .1 and regression lines accounted for more than 92% of the (log ratio) variance in response rates.

Figure 4 shows logarithms of ratios of response rates plotted as a function of logarithms of ratios of reinforcement rates for each of the five component subintervals. Equations of least squares regression lines and standard errors of estimate are given in each panel. Slopes decreased systematically across subintervals in all cases. That is, sensitivity decreased as a function of time since component alternation. For each bird, the largest decrease was found between the first and second subintervals. Performances of P-17, P-24, and P-26 in initial subintervals were highly sensitive to changes in reinforcement ratios—values of a were .85, .77, and .68 respectively, approaching the degree of sensitivity normally obtained in concurrent variable-interval schedules (de Villiers, 1977; Lobb & Davison, 1975; Myers & Myers, 1977). For P-12, changes in sensitivity over subintervals were only moderate. For all birds, sensitivity was constant after the third subinterval.

In summary, within-component changes in absolute response rate (Figure 1) were not reflected in changes in the extent of behavioral contrast but revealed a maximum between-component response rate differential in the first subintervals which inflated response ratios. Sensitivity was therefore highest at the beginning of components. Since behavioral contrast was invariant across subintervals, the sensitivity

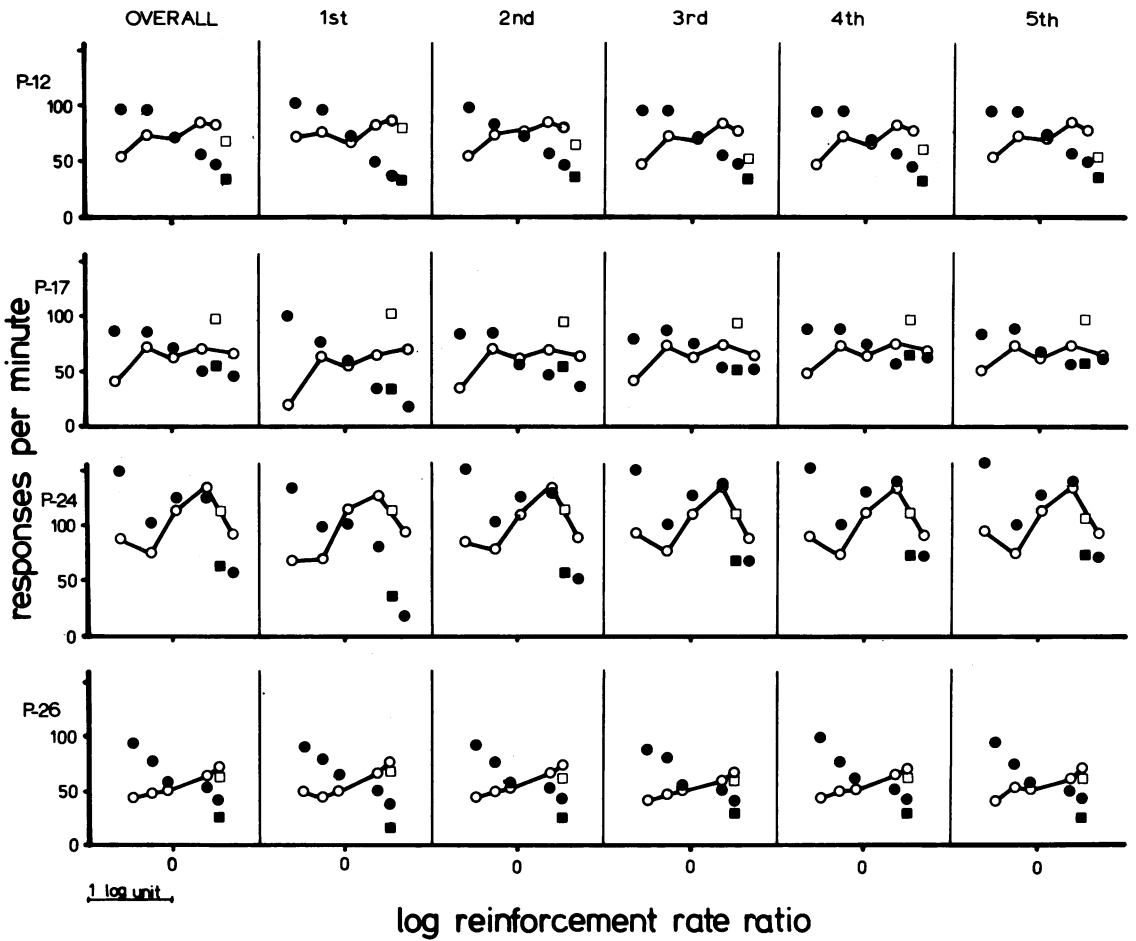


Fig. 2. Absolute response rates in each component plotted as a function of logarithm of reinforcement ratio. Extreme left panels show overall rates, and other panels show rates in individual subintervals. Rates in VI 60-sec components are represented by unfilled symbols.

changes occurred primarily because the extent to which response rates in the changed component varied with reinforcement ratios decreased over component subintervals (Figure 2).

DISCUSSION

Absolute response rate changes within components (i.e., as a function of time since component alternation) revealed instances of positive and negative local contrast, although these did not appear reliably across multiple schedule conditions. In particular, neither effect was as strong in the constant component (VI 60-sec in S1) as in the changed component.

Malone (1976) suggested that unless a multiple schedule discrimination is made difficult by

the use of relatively indiscriminable stimuli, local contrast will dissipate with prolonged exposure to constant experimental conditions. In the present experiment, the stimuli were clearly discriminable and training was continued in each multiple schedule until daily performances had stabilized, and the conditions were therefore not optimal for local contrast. The data are consistent with Malone's suggestion in that steady-state local contrast was strongest and most frequent in S2 where it was apparently maintained by frequent changes in reinforcement rate, and dissipated in S1 where the reinforcement rate was constant across the first five conditions. Indeed, examination of performances in earlier days of training in each condition revealed increasing local contrast to a maximum around the tenth day, but only for

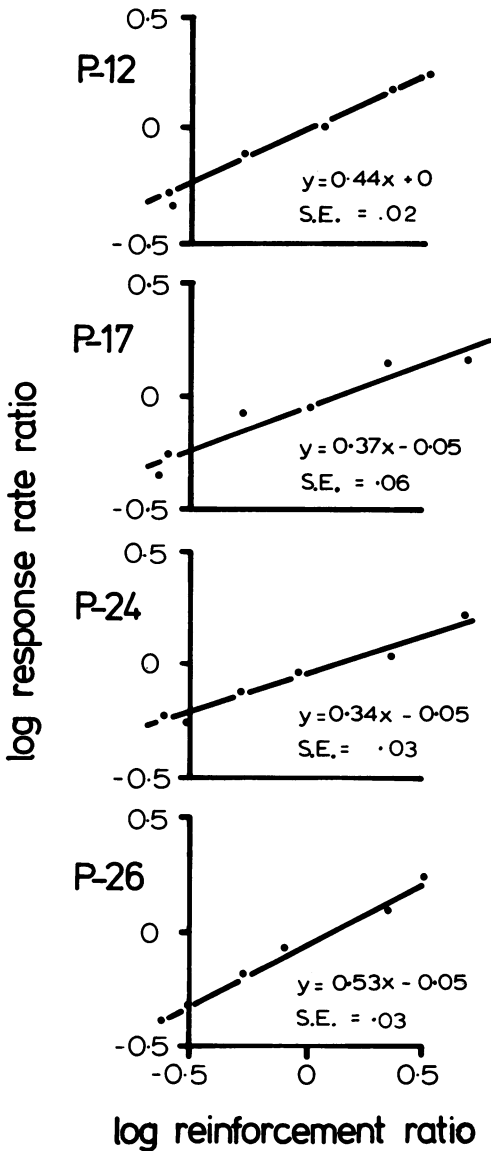


Fig. 3. Logarithms of ratios of overall response rates plotted as a function of logarithms of reinforcement ratios. Equations of least squares regression lines, and standard errors of estimate, are given in each panel.

the changed component. In Condition 6, the change in S1 (and S2) reinforcement rate apparently reinstated local contrast in both components for all birds.

Since local contrast was weaker and less frequent in the constant component, the extent of the variation in absolute response rate as a function of reinforcement ratio (Figure 2) decreased across subintervals only in the changed component. Behavioral contrast (in the con-

stant component) did not change reliably as a function of time since component alternation because local contrast in the constant component was not always sufficient to offset the occasional instances of reverse effects (positive and negative local induction).

The appearance of local contrast in stable performance in some conditions indicates that local contrast may contribute to sensitivity of response ratios to reinforcement ratios in steady-state multiple schedule performance. Temporal patterns of response rate within components revealed a maximum between-component differential in initial response rates, the magnitude of which was highly sensitive to reinforcement ratios. Sensitivity decreased as rates converged towards the end of components.

Menlove (1975) investigated changes in response proportions [$P_1/(P_1 + P_2)$] in mult VI 4-min VI 1-min and mult VI 1-min VI 4-min as a function of time since component alternation, a manipulation similar to that employed in the present study. Responses were recorded in 5-sec subintervals of 180-sec components. For one bird, response proportions in both multiple schedules were close to reinforcement proportions at the beginning of components and deviated towards indifference as components progressed. For two other birds, trends in response proportions were obscured by variability, although for one, mean response proportions (across replications) appeared to decrease as components progressed. Baum (1974) has shown however that assessment of undermatching by comparison of response and reinforcement proportions can be misleading, since this analysis confounds sensitivity with response bias. Moreover, in the absence of a number of conditions of differential reinforcement rate, reliable estimates of a and c (Equation 1) cannot be obtained, and it is therefore impossible to assess the extent to which the apparent increases in undermatching in Menlove's study were independent of shifts in response bias as a function of time since component alternation. In the present study, the use of six multiple schedules enabled a bias-free assessment of changes in undermatching (a) within components. Figure 3 showed that consistent shifts in response bias did occur within components for two birds, although at present these cannot be explained. In all birds of the present study, however, there were clear increases in under-

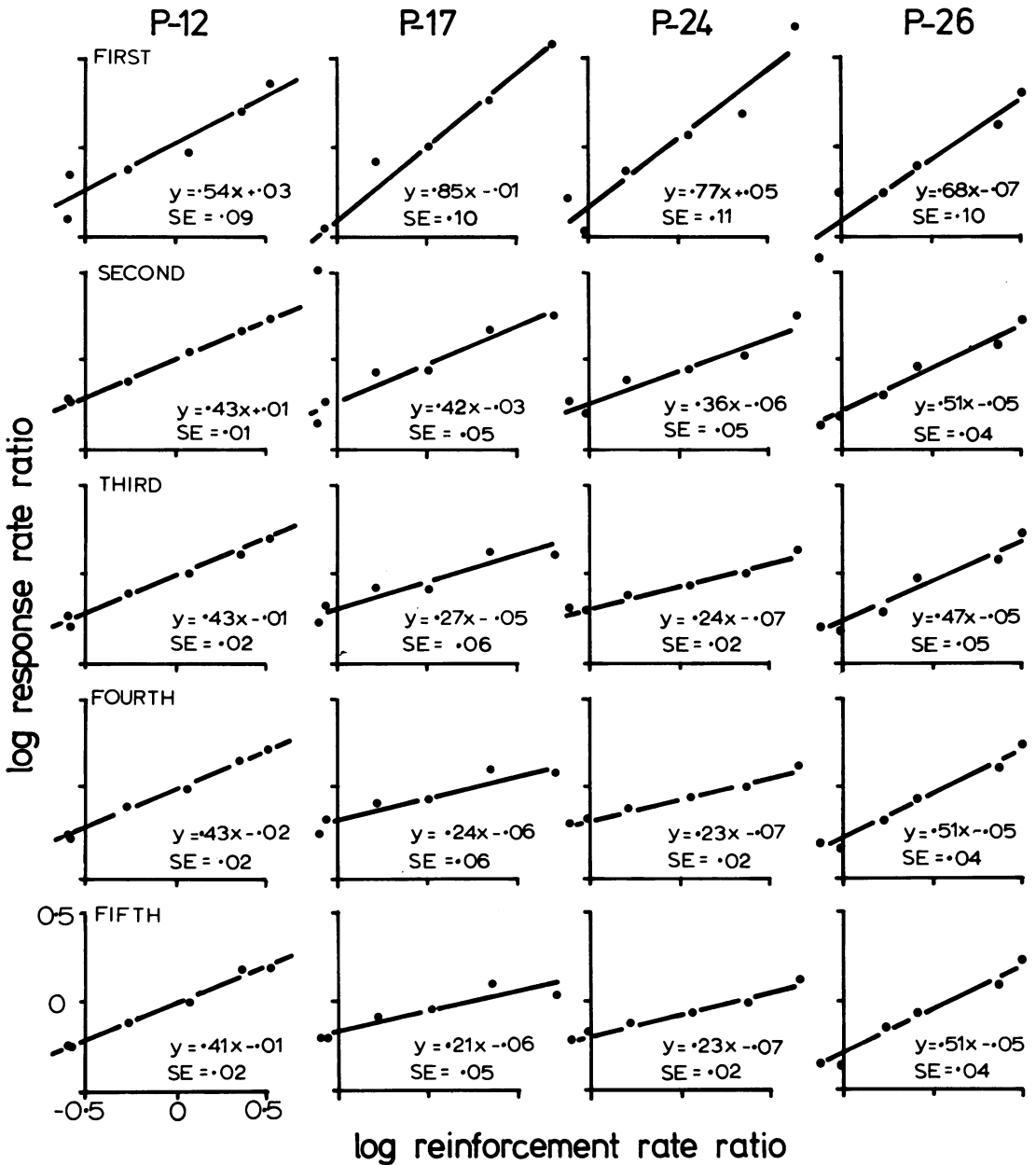


Fig. 4. Logarithms of ratios of response rates plotted as a function of logarithms of reinforcement ratios. Each column shows performance of a single subject in each successive component subinterval.

matching within components which were independent of changes in response bias.

Shimp and Wheatley (1971) compared response proportions in conditions where components alternated at intervals (component durations) of 2, 5, 10, 30, 60, or 180 sec. At component durations of 5 sec, response proportions closely approximated reinforcement proportions for each of three birds. At longer compo-

nent durations, response proportions deviated clearly towards indifference in two cases, suggesting increases in undermatching. Todorov (1972) obtained a similar result up to component durations of 300 sec. However, neither study employed sufficient conditions of differential reinforcement rate at each component duration to constitute a parametric investigation of changes in sensitivity as a function of

component duration. Shimp and Wheatley used five reinforcement proportions with 5-sec components but only two with longer components, and Todorov used only one reinforcement proportion. Our fit of Equation 1 to Shimp and Wheatley's data from 5-sec components gave a s of .94, .98, and .92, which are higher than values of a normally found in multiple schedules (e.g., .33 for 180-sec components; Lander & Irwin, 1968). Therefore, whereas no single study has systematically investigated this relationship, cross-experiment comparison does indicate an effect of component duration on sensitivity.

The sensitivity changes observed within components in the present study can account for the apparent effect of component duration on undermatching. In short component differential multiple schedules response rates are sampled soon after component alternation, when they are such that the between-component response differential is large. For short (5-sec) components, sensitivity would therefore be high. For longer components, high sensitivity at the beginning of components would be averaged with lower sensitivity at later stages, with a resulting increase in undermatching.

The absence of a sensitivity change after the third subinterval in the present data contrasts with the findings of component duration manipulations which suggested that undermatching continues to increase over much greater intervals (180 sec for Shimp and Wheatley, 300 sec for Todorov). It seems likely that initial response rate effects inflated average response proportions at all component durations in Shimp and Wheatley's and Todorov's experiments. This averaging artifact would necessarily decrease with long component durations, producing apparent increases in undermatching after local sensitivities had stabilized. Changes in sensitivity in the present study were not confounded in this way because a was estimated independently for performances in individual subintervals. We conclude, therefore, that the effect of the temporal separation of components is restricted to a short period after components alternate.

In summary, we have demonstrated response rate changes within multiple-schedule components in steady-state data. These changes were primarily restricted to the changed component and were associated with decreasing sensitivities of response ratios to reinforcement ratios

with increasing time since component alternation. This change in undermatching was not related to behavioral contrast in the constant component in that contrast remained invariant with time since component alternation.

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