SUCCESSIVE INDEPENDENCE OF MULTIPLE-SCHEDULE COMPONENT PERFORMANCES

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In three experiments, pigeons' responses were reinforced on two keys in each component of a series of multiple-schedule conditions. In each series, concurrent variable-interval schedules were constant in one component and were varied over conditions in the other component. In the first experiment both components arranged the same, constant total number of reinforcers, in the second the two components arranged constant but different totals, and in the third experiment the total was varied in one component and remained constant in the other. Relative reinforcer rate during the varied component was manipulated over conditions in all three experiments. In all these experiments, response and time allocation in the constant component were invariant when reinforcer ratios varied in the other component, demonstrating independence of behavior allocation in a multiple-schedule component from the relative reinforcer rate for the same alternatives in another component. In the two experiments which maintained constant reinforcer totals in components, sensitivity to reinforcement in the multiple schedules was the same as that in the concurrent schedules arranged during the varied component, with multiple-schedule bias in the experiment in which the totals were unequal.

Key words: multiple schedules, concurrent schedules, sensitivity, bias, extraneous reinforcers, key peck, pigeons

This work addresses the question of whether performance in one component of a multiple schedule is influenced by reinforcers obtained during another, temporally distinct component. This question has been studied most extensively by examining changes in the absolute rate of responding in one component as a function of changes in reinforcement during another component (Williams, 1983). Behavioral contrast refers to an opposite change in response rate, during a constant component of a multiple schedule, observed when reinforcer rate is changed during an alternated, varied component. It is usually regarded as strong evidence that reinforcers obtained in one component can influence behavior during a temporally distinct component.

An alternative strategy for investigating dependence among successive components is to study the dependence of behavior allocation in one component on relative reinforcer rates ob-

tained during an alternative component. It is commonly acknowledged that a multiple-schedule component offers a choice between reinforcers (R) obtained by operant responses (P) versus "extraneous" reinforcers (R_o) obtained by engaging in behavior (P_o) other than the operant defined by the experimenter (Herrnstein, 1970; McLean & White, 1983; Staddon, 1982). McLean and White (1983) showed that the phenomena of undermatching and response bias in multiple schedules can be understood from a consideration of these concurrently available reinforcers obtained during components, provided it was assumed that behavior allocation in a component is independent of reinforcers obtained during the alternated component. Accordingly, the present research examined behavior allocation between explicitly observable response alternatives in a component, and investigated how it depends on the reinforcement conditions prevailing in an alternated component.

A Model for Multiple-Schedule Performance

McLean and White (1983) proposed the following equation for the relation between ratios of response rates in components and ratios of reinforcer rates in components:

$$\frac{P_1}{P_2} = \left[\frac{R_1}{R_2} \right]^a \cdot \frac{R_2^a + bR_{O2}^a}{R_1^a + bR_{O1}^a} \quad (1)$$

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In Equation 1, P and R are local response and reinforcer rates, respectively. That is, they represent the number of responses or reinforcers in a multiple-schedule component divided by the time spent in the component. The subscripts 1 and 2 identify the components in which the responses or reinforcers occur. R_{O1} and R_{O2} are the rates at which extraneous reinforcers (Herrnstein, 1970) are obtained in Components 1 and 2, respectively.

Equation 1 results from combining equations for absolute response rates in the two components. The absolute rate equation is a generalized version of Herrnstein's (1970) equation for responding in single schedules and describes performance in a component in terms of reinforcers obtained in the same component. Behavior that occurs in Component 1 is distributed between two types of response— P_1 (responding on the multiple schedule) and P_{O1} (engaging in any other behavior). The way in which behavior is distributed between these response types depends on the relative values of the reinforcers that maintain them (R_1 vs. R_{O1} , respectively) and does not depend on reinforcers obtained during Component 2 (R_2 and R_{O2}). The constant a quantifies the sensitivity of behavior allocation to changes in the relative rates or values of R_1 and R_{O1} , and b quantifies bias which may favor one or another response topography independently of reinforcement (Baum, 1974). McLean and White arranged an experimental analog of R_O in each component of multiple schedules and showed that multiple-schedule undermatching and bias with respect to successive components of multiple schedules could be manipulated as predicted by Equation 1.

Successive Independence

The derivation of Equation 1 from two independent absolute-rate equations, each containing terms for reinforcers in only one component, assumes that reinforcers obtained during a component have no direct effect on behavior allocation during the other component. However, the observation of successive dependence of absolute response rates in multiple schedules (i.e., behavioral contrast) suggests that this assumption needs direct empirical support. That is, it may be that response allocation in a component depends on reinforcers obtained during both components, as absolute response rates seem to. McLean and

White proposed the following equation to describe the possible dependence of behavior allocation in Component 1 on reinforcers in Component 2:

$$\frac{P_1}{P_{O1}} = c \cdot \left[\frac{R_1}{R_{O1}} \right]^a \cdot \left[\frac{R_2}{R_{O2}} \right]^n \quad (2)$$

In Equation 2, n quantifies the extent to which the reinforcer ratio in Component 2 affects the allocation of behavior during Component 1, the constant a is defined as before, and $c = 1/b$. For the assumption of successive independence, $n = 0$ because Component 2 reinforcers are assumed to exert no influence over Component 1 behavior allocation. For negative values of n , Equation 2 predicts an inverse relation between the Component 2 reinforcer ratio and Component 1 response allocation (behavioral contrast in response allocation).

Experimental Analysis

To study the dependence of response ratios in one component of a multiple schedule on the reinforcer ratio during the other component, it is necessary to make R_O and P_O explicit. In a multiple schedule, this is done by arranging explicit, concurrently programmed reinforcers for responses on a second key during each component. Although the resulting analog values for R_{O1} and R_{O2} represent only a part of the total extraneous reinforcement obtained by the subject during components, the analogy has proven useful in illustrating the concurrent interactions which occur during multiple-schedule components and the effects of these interactions on multiple-schedule performance (McLean & White, 1983; Pliskoff, Shull, & Gollub, 1968). In this procedure (called a multiple-concurrent schedule), two stimuli (S_1 and S_2) alternate in succession. In Component 1 S_1 is presented on the left and right response keys, and in Component 2 S_2 is presented on both keys. In each component, reinforcers are arranged for responses on the left and right keys according to concurrent variable-interval variable-interval (VI) schedules.

If behavior allocation during a component depends on reinforcement in another component, variation of the reinforcer ratio on the two keys in one multiple-concurrent schedule component will produce changes in the response ratio on the two keys during a second

component. These changes in response ratios will be observed if the reinforcer ratio in the second component is held constant. Thus, to study the dependence of behavior allocation between concurrently available response alternatives P_1 and P_{O1} on alternate-component reinforcers R_2 and R_{O2} (i.e., to study the value for n in Equation 2) the present research poses the question of whether behavior allocation between *explicitly programmed* concurrent alternatives depends on reinforcement for the alternatives in another component. For left (L) and right (R) keys in multiple-concurrent schedules, three experiments are presented that obtain empirical estimates for n in a version of Equation 2:

$$\frac{P_{L1}}{P_{R1}} = c \cdot \left[\frac{R_{L1}}{R_{R1}} \right]^n \cdot \left[\frac{R_{L2}}{R_{R2}} \right]^n \quad (3)$$

In each of the three experiments, the reinforcer ratio across keys in one of the components was always constant whereas that in the alternated component was varied over conditions. It was therefore possible to ask whether behavior allocation between keys in one component is a function of the reinforcer ratio during an alternated, varied component, and to quantify the extent to which it is sensitive to alternate-component reinforcer ratios.

EXPERIMENT 1

In Experiment 1, the scheduled reinforcer rates on left and right keys were varied over several conditions in Component 1, whereas in Component 2 they remained equal and constant. The reinforcer total scheduled for Component 1 was the same as that scheduled for Component 2. Successive independence was studied by assessing changes in response ratios during Component 2 as a function of the variation in reinforcer ratios in Component 1. Invariance of response ratios in Component 2 would be evidence of successive independence.

METHOD

Subjects

Four homing pigeons, each with previous training in multiple-concurrent schedules of reinforcement (McLean & White, 1983) were maintained at $80 \pm 5\%$ of their free-feeding weights. Water and grit were always available in home cages, and supplementary feed given

at the end of daily sessions helped maintain prescribed body weights.

Apparatus

A lightproof, sound-attenuating chamber, 35 by 33 by 34 cm, contained the interface panel. Two 2.5-cm-diameter response keys were 25 cm from the floor and 9 cm to either side of the center of the interface panel. A hopper was centrally located in the interface panel and 8 cm from the floor. Each key was illuminated red (S1) or green (S2) and pecks exceeding about 0.2 N produced 0.05-s key-light offset. Reinforcers 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. Standard electro-mechanical programming apparatus and electronic timers, located in an adjacent room, scheduled and recorded all experimental events.

Procedure

Responses on two keys were reinforced according to independent Fleshler-Hoffman (1962) VI schedules, at different rates depending on whether keys were illuminated red (Component 1) or green (Component 2). Component durations were always 90 s and component stimuli alternated in direct succession. Any response on either key that directly followed a response on the other key constituted a changeover and was not reinforced. Changeovers initiated a 1.5-s changeover delay during which no responses were reinforced and which was reinitiated if another changeover occurred. The concurrent schedule accompanied by S2 always arranged reinforcers at the rate of 40 per hour on each key and that accompanied by S1 was varied in such a way as to maintain a constant scheduled total of 80 per hour. The schedule combinations for S1 and S2 are given in the upper part of Table 1, and the lower part gives the conditions in order of exposure and sessions to stability (in parentheses), which were different for each bird.

Conditions were maintained for at least 25 sessions and were then changed when a stability criterion had been met. The criterion was that for five consecutive sessions, the multiple-schedule response proportion on the left key ($P_{L1}/(P_{L1} + P_{L2})$) did not deviate by more than .025 from the mean response proportion calculated over those five sessions. If perfor-

Table 1

Schedule combinations, orders of exposure and sessions to stability (in parentheses) in Experiment 1. Each subject's first condition was replicated at the end of the series.

Con- dition	Schedule combinations			
	S1 (varied)		S2 (constant)	
	Left	Right	Left	Right
1	VI 6	VI 0.85	VI 1.5	VI 1.5
2	VI 3	VI 1	VI 1.5	VI 1.5
3	VI 2	VI 1.2	VI 1.5	VI 1.5
4	VI 1	VI 3	VI 1.5	VI 1.5
5	VI 0.85	VI 6	VI 1.5	VI 1.5

Condition number in order of exposure and sessions to stability

Bird	1st	2nd	3rd	4th	5th	6th
A1	2 (30)	5 (25)	4 (25)	1 (47)	3 (25)	2 (38)
A2	4 (33)	5 (29)	1 (26)	2 (26)	3 (25)	4 (30)
A3	1 (27)	4 (25)	5 (34)	2 (25)	3 (25)	1 (26)
A4	4 (25)	5 (25)	1 (31)	2 (43)	3 (25)	4 (29)

mance was not stable after 55 sessions in a condition, the data were discarded and the condition was repeated later. In any case, each bird's first condition was replicated at the end of the series.

Performance measures, obtained separately in the presence of S1 and S2, were local response and reinforcer rates on each key (responses on a key in a component divided by a time base for the component) and time allocated to the left key (time elapsed between a changeover to the left key and the subsequent return to the right key, less left key reinforcement time, divided by the time base).

Variable-interval and time-allocation timing for a multiple-schedule component stopped as soon as components alternated. The time base for each component was the total time spent in a component minus total reinforcement time in that component.

RESULTS AND DISCUSSION

Data from each condition are given in the Appendix. Figure 1 shows the concurrent performances observed during each of the two components. Right panels show logarithms of response ratios for the constant component ($\log_{10}(P_{L2}/P_{R2})$) plotted as a function of logarithms of reinforcer ratios in the varied component ($\log_{10}(R_{L1}/R_{R1})$). Over different conditions, the response ratios observed in the constant component appeared virtually invar-

iant. Least-squares regression lines are shown with the origin indicated by a cross, and their equations and standard errors of estimate are given for each bird. On these co-ordinates, the functions are plots of a logarithmic version of Equation 3 for concurrent performances: in S2,

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

Provided the observed S2 reinforcer ratio (R_{L2}/R_{R2}) is always close to its scheduled value of 1.0, the slopes of the fitted lines directly estimate n and the intercepts give the value for $\log c$ (because $\log_{10}(R_{L2}/R_{R2}) = 0$). These estimates for n were not consistently positive or negative across subjects, and did not deviate from zero by more than .10 for any subject. That is, the performances observed in this experiment indicate successive independence ($n = 0$).

Left panels of Figure 1 show logarithms of ratios of responses in the varied component ($\log_{10}(P_{L1}/P_{R1})$), also plotted as a function of varied-component reinforcer ratios. Least-squares regression lines are drawn as before, and their equations and standard errors of estimate are given. These functions are plots of the generalized matching relation for concurrent choice (Baum, 1974), which is equivalent to Equation 3 with $n = 0$. That is,

$$\frac{P_L}{P_R} = c \cdot \left[\frac{R_L}{R_R} \right]^a. \quad (5)$$

The slopes of these lines are estimates of concurrent sensitivity. All slopes indicate under-matching ($a < 1.0$) of concurrent response ratios to concurrent reinforcer ratios, and are somewhat lower than typical concurrent sensitivities which lie in the range of .80 to 1.0 (de Villiers, 1977; Myers & Myers, 1977). It is unlikely that this low sensitivity arose from the alternation of conditions every 90 s, however, because if that were so the same alternation of conditions would be expected to affect behavior in the constant component. Despite the low values for a in Component 1, these data demonstrate clear sensitivity of response allocation in a component to reinforcer ratios in the same component.

Figure 2 shows the same analyses for con-

Fig. 1. $\log_{10}$ concurrent response ratios for each of 4 pigeons in Experiment 1, shown separately for the varied component (left panels) and the constant component (right panels), both plotted as a function of $\log_{10}$ concurrent reinforcer ratios during the varied component. Equations of least-squares regression lines and standard errors of estimate (SE) are given for each bird. In each case, the origin is marked by a cross, and the vertical and horizontal scales are identical.

current-schedule time allocation during components. In performances during the constant component (right panels) slopes of regression lines again did not deviate reliably from zero and did not exceed standard errors of estimate

in individual cases except for Bird A3. Slopes in S2 did not differ consistently from those for response ratios, given in right panels of Figure 1. Time ratio sensitivity during S1 (left panels) was not consistently different from the re-

Fig. 2. $\log_{10}$ concurrent time ratios for each of 4 pigeons in Experiment 1, shown separately for the varied component (left panels) and the constant component (right panels), both plotted as a function of $\log_{10}$ concurrent reinforcer ratios during the varied component. Equations of least-squares regression lines and standard errors of estimate (SE) are given for each bird. In each case, the origin is marked by a cross, and the vertical and horizontal scales are identical.

sponse ratio sensitivities in left panels of Figure 1.

Small changes in obtained reinforcer ratios occurred during the constant component over

conditions, despite constant scheduled reinforcer rates on the two keys. Multiple regression estimates for a and n were therefore taken by fitting Equation 4 using obtained S1 and S2

reinforcer ratios and are given in Table 2 for each bird, for response ratios and for time ratios. The multiple regression estimates did not differ appreciably or consistently from the estimates given in Figures 1 and 2, which assumed perfect constancy of R_{L2}/R_{R2} . Proportions of variance in obtained log ratios accounted for by predictions from Equation 4 (VAC) indicate that Equation 4 in general described performances in the two components well.

To summarize, the concurrent performances observed during components in this experiment indicate that (a) response and time allocation during a component of a multiple-concurrent schedule are sensitive to the relative rate of reinforcers for alternative responses in the same component (i.e., $a > 0$ in Equation 4), and (b) response and time allocation during a component are insensitive to the relative rate of reinforcers for the same alternatives in a temporally distinct component (i.e., $n = 0$ in Equation 4). That is, the results are consistent with successive independence.

Multiple-Schedule Performances

The contingencies arranged for each key in the two successive components constituted a pair of concurrently available multiple schedules. Figure 3 shows multiple-schedule analyses of these data. Left panels show logarithms of response ratios on the left key (i.e., $\log_{10}(P_{L1}/P_{L2})$; unfilled circles) and on the right key ($\log_{10}(P_{R1}/P_{R2})$; filled circles). Logarithms of response ratios on a key are plotted as a function of logarithms of reinforcer ratios on the same key. The slopes of these functions index multiple-schedule sensitivity according to a version of the generalized matching law for multiple-schedule performance (Baum, 1974; Lander & Irwin, 1968):

$$\frac{P_1}{P_2} = q \cdot \left[\frac{R_1}{R_2} \right]^m, \quad (6)$$

where the interpretations of q and m are similar to those of c and a (respectively) above. According to the standard errors for the fitted regression equations given in Figure 3, the generalized matching relation fitted obtained log response ratios well. The slopes (m) in Figure 3 were not consistently different (across subjects) from the concurrent sensitivities given in left panels of Figure 1, and did not differ from them substantially in individual cases.

Table 2

Multiple regression estimates of a and n (Equation 2) for response and time ratios in Experiment 1. VACs are proportions of variance in obtained log ratios accounted for by predictions from Equation 4.

Bird	a	n	VAC
Response ratios			
A1	.51	-.09	.94
A2	.63	.02	.99
A3	.27	.08	.46
A4	.58	-.10	.90
Time ratios			
A1	.62	-.04	.95
A2	.74	.05	.99
A3	.42	.09	.82
A4	.56	-.03	.85

Right panels show logarithms of multiple-schedule time ratios plotted as a function of multiple-schedule reinforcer ratios, with left- and right-key performances again represented by unfilled and filled circles, respectively. Again, the generalized matching relation described obtained log ratios well, and time-ratio sensitivities in Figure 3 were not appreciably or consistently different from the concurrent time-ratio sensitivities in the left panels of Figure 2. Thus multiple and concurrent sensitivities were equal in this experiment, both for response ratios and for time ratios.

Independent Component Performances

The finding of invariant constant-component behavior allocation (successive independence) in this experiment indicates that behavior allocation during a component of a multiple-concurrent schedule depends on the relative rate of reinforcement for response alternatives in the same component, but not on the relative reinforcer rate for the same alternatives in another component. For the concurrent alternatives offered during a component of a regular multiple schedule, then, performance during components can be described by the generalized matching law (Equation 5) without the inclusion of a term for reinforcers obtained in the other component. Equation 5, for the concurrent choice offered during a regular multiple-schedule component, can be rewritten thus (with $c = 1/b$):

$$\frac{P_1}{P_1 + P_{O1}} = \frac{R_1^a}{R_1^a + bR_{O1}^a}$$

and in Component 2

$$\frac{P_2}{P_2 + P_{O2}} = \frac{R_2^a}{R_2^a + bR_{O2}^a}$$

Identical equations can be written for relative time allocation ($T_1/(T_1 + T_{O1})$ and $T_2/(T_2 + T_{O2})$). As shown by McLean and White (1983), Equation 1 can be derived by dividing these equations for performance in the two components:

$$\frac{\frac{P_1}{P_1 + P_{O1}}}{\frac{P_2}{P_2 + P_{O2}}} = \left[\frac{R_1}{R_2} \right]^a \cdot \frac{R_2^a + bR_{O2}^a}{R_1^a + bR_{O1}^a}$$

The left-hand side of Equation 2 reduces to a simple ratio because the sums $T_1 + T_{O1}$ and $T_2 + T_{O2}$ equal the total time spent in the (equal duration) components, and therefore cancel. Similarly, $P_1 + P_{O1}$ and $P_2 + P_{O2}$ each sum to k , the constant total behavioral output per unit of time (Herrnstein, 1970), and therefore cancel.

The usual finding in comparisons of multiple- and concurrent-schedule performances is that response differentials between components are greater in concurrent schedules than in multiple schedules with the same reinforcer ratio. That is, a in Equation 5 is greater than m in Equation 6. Thus when reinforcer ratios are varied in the two schedule arrangements, changes in response ratios reveal greater sensitivity to reinforcement in the concurrent schedules (for direct comparisons, see Charman & Davison, 1982; Lobb & Davison, 1977; McLean & White, 1983). By contrast, the multiple-schedule performances in the present experiment revealed equal multiple and concurrent sensitivities, both for response ratios and for time ratios. Equation 1 predicts this equality in conditions in which the total reinforcers obtained in each component, $R_1 + R_{O1}$ and $R_2 + R_{O2}$, remain constant. This prediction arises because under such conditions, the term for reinforcer totals in Equation 1, $(R_2^a + bR_{O2}^a)/(R_1^a + bR_{O1}^a)$, remains approximately constant when multiple-schedule reinforcer

ratios R_1/R_2 are varied over conditions. That is, if total reinforcers in the two components are maintained at a constant value over conditions, as was the case in this experiment, Equation 1 becomes equivalent to the multiple-schedule generalized matching law (Equation 6), with $m = a$. Under regular multiple scheduling, small constant values for R_{O1} and R_{O2} will mean that the ratio of component reinforcer totals varies inversely with changes in the multiple-schedule reinforcer ratio, and Equation 1 predicts reduced multiple sensitivity. Data from this experiment therefore support Equation 1 by demonstrating equal multiple and concurrent sensitivity when the total obtained reinforcement is constant in each component over conditions, and also by confirming the successive independence assumed in its derivation.

EXPERIMENT 2

In Experiment 1 it was shown that response and time ratios observed during a constant component were invariant when reinforcer ratios in the alternated component were varied over conditions. In a similar manipulation in discrete-trials multiple-concurrent schedules, Nevin, Mandell, and Whittaker (1978) sometimes found changes in constant-component response allocation. In their procedure, constant-component responding was reinforced on two keys at different but constant rates, and responding in the alternated component was reinforced on one key or the other in different conditions. Especially when constant-component reinforcer rates were *low* relative to the reinforcer rate in the varied component, constant-component response allocation changed in the same direction as reinforcer allocation in the varied component. In conditions in which their two components arranged *equal* overall rates of reinforcement, Nevin et al. found smaller and less reliable changes in constant-component response allocation. They related their greater successive dependence in a lower valued constant component to absolute-rate behavioral contrast and induction, which are also

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Fig. 3. Log₁₀ multiple-schedule response ratios (left panels) and time ratios (right panels) for each of 4 pigeons in Experiment 1 for the left key (unfilled circles) and the right key (filled circles) plotted as a function of logarithms of left-key or right-key multiple-schedule reinforcer ratios. Equations of least-squares regression lines and standard errors of estimate (SE) are given for each bird. In each case, the origin is marked by a cross, and the vertical and horizontal scales are identical.

Table 3

Schedule combinations, orders of exposure, and sessions to stability (in parentheses) in Experiment 2. Each subject's first condition was replicated later.

Condition	Schedule combinations			
	S1 (constant)		S2 (varied)	
	Left	Right	Left	Right
1	VI 6	VI 3	VI 6	VI 0.75
2	VI 6	VI 3	VI 3	VI 0.85
3	VI 6	VI 3	VI 2	VI 1
4	VI 6	VI 3	VI 1.5	VI 1.2
or	VI 6	VI 3	VI 1.2	VI 1.5
5	VI 6	VI 3	VI 1	VI 2
6	VI 6	VI 3	VI 0.85	VI 3
7	VI 6	VI 3	VI 0.75	VI 6

Condition numbers in order of exposure and sessions to stability

Bird	1st	2nd	3rd	4th	5th	6th	7th	8th
A1	7 (38)	2 (28)	5 (63)	6 (41)	3 (55)	7 (39)	1 (34)	4 (30)
A2	3 (29)	5 (37)	2 (32)	7 (25)	1 (29)	6 (25)	4 (37)	3 (27)
A3	5 (25)	3 (31)	4 (29)	1 (35)	7 (31)	2 (49)	6 (51)	5 (25)
A4	4 (36)	7 (37)	3 (55)	6 (30)	2 (41)	1 (25)	5 (40)	4 (33)
A5	6 (45)	1 (31)	7 (44)	5 (71)	3 (69)	2 (25)	4 (20)	6 (67)
A6	3 (26)	4 (25)	5 (27)	2 (26)	7 (30)	1 (26)	6 (26)	3 (31)

more pronounced when responding is reinforced infrequently (Nevin, 1974; Spealman & Gollub, 1974).

Experiment 2 examined successive independence in multiple-concurrent schedules under conditions in which a constant Component 1 delivered an overall low rate of reinforcement. Reinforcer ratios were varied in an alternated Component 2, which delivered a constant and relatively high overall rate of reinforcement.

METHOD

Subjects

The 4 birds used in Experiment 1, and 2 others with previous training in multiple-concurrent schedules (McLean & White, 1983), served as subjects.

Apparatus and Procedure

The apparatus was the same as that in Experiment 1. The procedure differed only in that the schedule combinations were different, and that conditions were maintained until performance was stable, even if this took more than 55 sessions. In all conditions, the concurrent schedule accompanied by S1 arranged a total of 30 reinforcers per hour (10 per hour on the left key and 20 per hour on the right). The concurrent schedule accompanied by S2 varied over conditions but always arranged a

total of 90 reinforcers per hour. Schedule combinations used in each condition, their order of exposure, and the number of sessions to stability for each bird are given in Table 3. Each bird's first condition was replicated later.

RESULTS AND DISCUSSION

Data from the final 5 days of performance in each of these conditions are given in the Appendix. Figure 4 shows the concurrent performances observed during each of the two components. Right panels of Figure 4 show logarithms of constant-component response ratios (unfilled circles) plotted as a function of logarithms of varied-component reinforcer ratios. Logarithms of constant-component reinforcer ratios are also shown (filled circles) and did not vary appreciably over conditions. Log response ratios in the constant component remained essentially invariant over changes in varied-component reinforcement and did not change relative to reinforcer ratios (filled circles) in the same component. The slopes of the regression lines in right panels did not deviate reliably from zero ($M = .05$) and were generally small relative to standard errors of estimate. The intercepts of the regression lines were all negative, because of the negative log reinforcer ratio ($-.48$) in the constant component (see Equation 4).

Fig. 4. $\log_{10}$ concurrent response ratios for each of 6 pigeons in Experiment 2, shown separately for the varied component (left panels) and the constant component (right panels), both plotted as a function of $\log_{10}$ concurrent reinforcer ratios during the varied component. Filled circles in right panels are $\log_{10}$ obtained reinforcer ratios in the constant component. Equations of least-squares regression lines and standard errors of estimate (SE) are given for each bird. In each case, the origin is marked by a cross, and the vertical and horizontal scales are identical.

Fig. 5. $\log_{10}$ concurrent time ratios for each of 6 pigeons in Experiment 2, shown separately for the varied component (left panels) and the constant component (right panels), both plotted as a function of $\log_{10}$ concurrent reinforcer ratios during the varied component. Filled circles in right panels are $\log_{10}$ obtained reinforcer ratios in the constant component. Equations of least-squares regression lines and standard errors of estimate (SE) are given for each bird. In each case, the origin is marked by a cross, and the vertical and horizontal scales are identical.

In the left panels of Figure 4, logarithms of varied-component response ratios are plotted as a function of logarithms of varied-component reinforcer ratios. As in Experiment 1, the slopes of the fitted regression lines indicate low (but nevertheless clear) sensitivity of behavior allocation in a component to reinforcer ratios in the same component. For Birds A1, A2, A3, and A4, which were also subjects in the previous experiment, the slopes and intercepts of these regression lines were essentially the same as in Experiment 1.

Figure 5 shows the same analyses for time allocations in the two components. The right panels of Figure 5, which give the performances in the constant component, show consistent increases in logarithms of constant-component time ratios as alternate-component log reinforcer ratios increased. That is, slopes of regression lines were always positive, indicating positive values for n . However, the slopes were generally low ($M = .08$) and were rarely larger than the standard errors of estimate, so there can be little confidence in this result.

Time-ratio sensitivity is given by the regression-line slopes in the left panels of Figure 5. Again, the slopes indicated consistent undermatching, and for Birds A1 through A4 they were not consistently different from those observed in Experiment 1. The intercepts of these regression lines were idiosyncratic, and as was the case for the intercepts in the left panels of Figure 4, they were not different from those in the varied-component performances in Experiment 1.

These idiosyncratic intercepts indicate that response and time ratios during the varied component were not influenced by the consistent 1:3 reinforcer ratio in the constant component. If there had been any influence of the constant-component reinforcer ratio on behavior allocation in the varied component, concurrent performances in the varied component would have been biased—an inverse bias in the case of negative values for n . However, for the 4 birds who served in both Experiment 1 and Experiment 2, there was no change in concurrent-schedule bias despite the use of a new constant-component reinforcer ratio in Experiment 2. Thus, this experiment demonstrates independence of behavior allocation in a component from reinforcer ratios in other components in two ways: (a) by showing in-

variant response and time ratios during the constant component when varied-component reinforcer ratios were changed, and (b) by showing no difference in varied-component bias from Experiment 1, despite the new constant-component reinforcer ratio.

Multiple-Schedule Performances

Figure 6 shows the same multiple-schedule analyses of data from these conditions as was given in Figure 3 for Experiment 1. Logarithms of response ratios are shown in the left panels, and data from the left-key multiple schedule are represented by unfilled circles. Filled circles are data from the right-key multiple schedule. Slopes of fitted least-squares regression lines in Figure 6 were not different from the concurrent response-ratio sensitivities observed during the varied component, given in Figure 4. Multiple-schedule bias always favored S1 (the constant component), and the mean intercept was .11. Right panels of Figure 6 show multiple-schedule time ratios treated the same way. As was the case for response ratios, multiple sensitivities (m) were about equal to the concurrent time-ratio sensitivities during the varied component (Figure 5) and bias favored the constant component (mean intercept = .23).

For the conditions arranged in Experiment 2, Equation 1 predicts equal sensitivities in the multiple schedules and the varied-component concurrent schedules (i.e., $m = a$). As was the case in Experiment 1, the total reinforcers arranged during the two components did not vary over conditions. In addition, however, the reinforcer total in one component was always greater than that in the other component in Experiment 2. Equation 1 predicts that if the total reinforcers in one component are consistently larger than those in the other component, then multiple-schedule bias will favor the component with the smaller reinforcer total (in this case, the constant component).

To summarize, Experiment 2 extended the finding of successive independence in Experiment 1 to conditions in which the constant component arranged a low overall rate of reinforcement relative to the overall rate in the varied component. These are conditions that have been shown to enhance absolute-rate behavioral contrast and also to enhance induction effects in constant-component response allocation in discrete-trials procedures (Nevin et

al., 1978). Successive independence was demonstrated in invariant constant-component response ratios over conditions in which alternated-component reinforcer ratios changed, as in Experiment 1. Successive independence was also demonstrated in that concurrent-schedule bias during the varied component was the same as in Experiment 1, despite a change in constant-component reinforcer ratio between Experiments 1 and 2. Multiple-schedule analyses of data from these conditions supported Equation 1 by showing equal sensitivity to reinforcement ratios in the multiple schedules and in the concurrent schedules, and by showing a consistent bias in the multiple schedules favoring the component with the lower overall reinforcer rate.

EXPERIMENT 3

Experiments 1 and 2 demonstrated successive independence by varying concurrent reinforcer ratios in one component without changing the total reinforcers arranged in either component. Catania (1961) arranged multiple-concurrent schedules in which one of the variable-interval schedules in a varied component was changed over conditions and the other remained constant. In the alternated component, both variable-interval schedules were constant. Thus Catania varied both the relative reinforcer rate and the overall reinforcer rate in the varied component, while keeping both constant in the other component. In Catania's first condition, only one concurrent schedule was presented. Then, in a second condition, another concurrent schedule (concurrent variable-interval extinction) was alternated with the first and arranged a lower overall rate of reinforcement. When this second schedule was introduced, group average response rates increased on both keys in the unchanged schedule. That is, response rates on both keys showed behavioral contrast in the constant schedule when a lower valued schedule was introduced. In a third condition, the value of the variable-interval schedule in the

introduced concurrent schedule was increased so that the overall rate of reinforcement in this component was equal to that in the constant component. This increase in total varied-component reinforcement in the third condition eliminated the contrast effect. Catania concluded that variation of the reinforcer *total* in the varied component is necessary for the appearance of behavioral contrast in the constant component.

Catania's result identifies one respect in which behavior in a multiple-schedule component depends on reinforcer rate in another component (i.e., behavioral contrast in absolute response rate). However, it is not clear from Catania's group average response rates whether these conditions produced successive dependence in response allocation. For example, if the contrast effects in the constant component were more or less equal on the two keys, Catania's absolute-rate behavioral contrast would have occurred along with successive independence in response allocation. However, if there had been more contrast on the key that was correlated with varied reinforcement in the alternated component (than on the key which was always constant), Catania's data would indicate successive interaction ($n < 0$) in response allocation as well as in absolute response rate.

Experiment 3 was conducted to examine successive independence in conditions which Catania showed were optimal for absolute-rate successive dependence in multiple-concurrent schedules. In one component, the reinforcer rate on both keys remained constant, as in Experiments 1 and 2. In the alternated component, reinforcer rate was varied on one key and remained constant on the other. Thus relative and (overall) absolute reinforcer rates were varied in this component, and both were constant in the other component. In addition, most conditions arranged that the reinforcer total in the constant component remained lower than that in the varied component, as in Experiment 2. Thus Experiment 3 optimized conditions for successive dependence.

←
Fig. 6. $\log_{10}$ multiple-schedule response ratios (left panels) and time ratios (right panels) for each of 6 pigeons in Experiment 2 for the left key (unfilled circles) and the right key (filled circles) plotted as a function of logarithms of left-key or right-key multiple-schedule reinforcer ratios. Equations of least-squares regression lines and standard errors of estimate (*SE*) are given for each bird. In each case, the origin is marked by a cross, and the vertical and horizontal scales are identical.

Table 4

Schedule combinations, orders of exposure, and sessions to stability (in parentheses) in Experiment 3. Two conditions were replicated for Bird A3.

Condition	Schedule combinations			
	S1 (constant)		S2 (varied)	
	Left	Right	Left	Right
1	VI 3	VI 6	VI 0.75	VI 6
2	VI 3	VI 6	VI 3	VI 6
3	VI 3	VI 6	VI 6	VI 6
4	VI 3	VI 0.85	VI 0.75	VI 0.85
5	VI 3	VI 0.85	VI 3	VI 0.85
6	VI 3	VI 0.85	VI 6	VI 0.85

Condition numbers in order of exposure and sessions to stability

Bird	1st	2nd	3rd	4th	5th	6th	7th	8th
A2	1 (26)	2 (33)	6 (26)	4 (25)	5 (31)	3 (25)		
A3	6 (27)	5 (36)	4 (43)	3 (31)	2 (32)	1 (26)	3 (35)	6 (25)
A4	1 (43)	2 (29)	3 (32)	4 (26)	6 (66)*			

* Never stable. Data from the last five of 66 sessions.

METHOD

Three of the 4 birds used in Experiment 1 (A2, A3, and A4) served as subjects. The apparatus and procedure were the same as in Experiment 2, except that the schedule combinations used (given in Table 4) were different. There were two short series of conditions. In one series the right-key reinforcer rate was 10 per hour in both components and in the other series it was 70 per hour in both components. In both series of conditions the scheduled left-key reinforcer rate was always 20 per hour in S1 and was varied in S2. Thus the contingencies on the left key constituted a multiple schedule with a constant component (S1) and a varied component (S2). The multiple schedule was presented in the context of either a high rate of concurrently available reinforcement (i.e., on the right key) or a low rate. The performance measures obtained were the same as in Experiments 1 and 2, and are given in the Appendix.

RESULTS AND DISCUSSION

The first question of interest in this experiment concerns whether absolute-rate behavioral contrast occurred during the constant component when the reinforcer total in the varied component was changed, regardless of the key on which it occurred. That is, do variations in reinforcer totals in a component promote successive dependence in absolute response rate in multiple-concurrent schedules,

as Catania's data suggest? This question was investigated by examining changes in S1 response totals (sum of rates on the two keys) as a function of changes in S2 reinforcer totals. The second question concerns whether there was more absolute-rate contrast during S1 on the left key (where S2 reinforcer rate was varied) than on the right key (where S2 reinforcer rate was constant within a series). If there was more contrast on the left key, then multiple-concurrent contrast would be attributed to response-ratio dependence ($n < 0$). This question was investigated by examining changes in S1 response rate on one key relative to the rate on the other key (i.e., response ratios) as a function of changes in S2 reinforcer ratios.

Reinforcer totals and reinforcer ratios during S2 were perfectly correlated, so analyses of absolute and relative response rates are therefore consistently presented as a function of S2 reinforcer ratios. Figure 7 shows the total constant-component response output, summed over both keys, plotted as a function of logarithms of varied-component reinforcer ratios. Data from Conditions 1 through 3 (R_{R1} and $R_{R2} = 10$ per hour) are represented by unfilled circles, and the scale for response rate is given on the left-hand side of the figure. Data from Conditions 4 through 6 are represented by filled circles and the response-rate scale is given on the right-hand side of the figure. Solid lines connect data from conditions within each series and (in the case of A3) average response totals

in replicated conditions. Constant-component response totals decreased as a function of increasing varied-component reinforcer ratios (and reinforcer totals) except in the case of Bird A3 in Conditions 1 through 3, which showed the reverse relation. For Bird A2 in Conditions 4 through 6, decreases in response totals were consistent across conditions but negligible. That is, of the six performances four showed clear behavioral contrast, one showed clear induction, and another showed no change. By comparison, response totals in the constant components of Experiments 1 and 2 showed no clear instances of contrast (see Appendix). The present experiments are therefore consistent with Catania's (1961) data in showing no contrast in conditions with constant reinforcer totals in components (Experiments 1 and 2), but some instances of contrast when varied-component reinforcer totals were changed (Experiment 3).

Behavior allocation data from the constant component are given in Figure 8. The two left columns in Figure 8 show logarithms of response ratios in the constant component plotted as a function of logarithms of reinforcer ratios in the varied component. The extreme left column gives data from Conditions 4 through 6, and the second column gives data from Conditions 1 through 3. Diamonds represent obtained log reinforcer ratios in the constant component, and circles represent log response ratios. Because there were few conditions in each series, regression lines were not fitted and data are simply connected by solid lines.

There was no compelling evidence of successive dependence in the data of Figure 8, and such evidence as there is favors a positive relation by contrast with the inverse relation suggested by the absolute response rates in Figure 7. For Bird A3, there were clear increases in constant-component log response ratios as a function of varied-component log reinforcer ratios in both series. Bird A2 showed slight increases in both series, and A4 showed a clear decrease in Conditions 4 through 6 and no change in Conditions 1 through 3. Right columns in Figure 8 give the same analyses for constant-component time allocation, and changes in each series were about the same as for response ratios.

Thus for behavior allocation, there were four instances of a positive relation (i.e., positive values for n), one of a negative relation (in-

Fig. 7. Overall response rate during the constant component for each of 3 pigeons in Experiment 3 for Conditions 1 to 3 (unfilled circles) and Conditions 4 to 6 (filled circles) plotted as a function of $\log_{10}$ concurrent reinforcer ratios in the varied component. The scales on the right-hand border are for Conditions 4 to 6 and those on the left border are for Conditions 1 to 3.

Fig. 8. $\log_{10}$ concurrent response ratios (first and second columns) and $\log_{10}$ concurrent time ratios (third and fourth columns) for each of 3 pigeons in Experiment 3 for the constant component plotted as a function of $\log_{10}$ concurrent reinforcer ratios in the varied component. Data are given separately for Conditions 4 to 6 (first and third columns) and Conditions 1 to 3 (second and fourth columns). Diamonds are $\log_{10}$ concurrent reinforcer ratios obtained during the constant component.

teraction; $n < 0$), and one of no change. Absolute-rate changes in Figure 7 gave four instances of interaction (i.e., an inverse relation), one of induction (a positive relation), and one of no change. Individual instances of absolute-rate behavioral contrast did not, therefore, seem to be associated with negative values for n , and conditions which promoted some absolute-rate interaction did not promote interaction in response or time allocation.

Response allocation data within the varied components in both series are given in the left panels of Figure 9. Logarithms of response ratios were a clear function of logarithms of reinforcer ratios in the same component, and the slopes of the regression lines given in Figure 9 indicate somewhat higher sensitivities than were observed for the same birds in Experiments 1 and 2. The right panels of Figure 9 give varied-component time allocation data treated the same way, and also show greater sensitivities than in Experiments 1 and 2. For response and time-ratio analyses, varied-component biases were idiosyncratic and did not differ from those observed in Experiments 1 or 2.

Greater sensitivities here than in the previous experiments might conceivably have arisen from the changes to the constant-component reinforcer ratio between series of conditions, although the invariance of constant-component behavior allocation makes this unlikely, because it would be a case of successive dependence. As a check, and to summarize data from the two series of conditions together, multiple regression estimates of a and n were obtained using data from all conditions. If the greater varied-component sensitivities in Experiment 3 reflected the influence of reinforcer ratios in the constant component, then multiple regression analysis would separate that influence out and return lower estimates for a . Table 5 gives the multiple regression estimates, which were not consistently different from those given in Figure 9. Multiple regression estimates of n confirmed the conclusion of successive independence from Figure 8 in that they did not differ consistently from zero.

GENERAL DISCUSSION

The main question addressed by these experiments concerned whether the allocation of behavior between various concurrently avail-

able response alternatives during a multiple-schedule component is independent of the relative rate of reinforcers for the same response alternatives obtained during a temporally distinct component. Each experiment examined this question by arranging two response keys in each component of a multiple schedule and varying the relative rate of reinforcers on the two keys in only one component.

In Experiments 1 and 2, the slopes of functions relating ratios of responses on the two keys in the constant component to reinforcer ratios in the alternated, varied component never deviated from zero by more than .10 and did not deviate reliably from zero in either experiment. For time allocation in the constant component, there were consistent positive slopes only in Experiment 2, and these were too small, relative to standard errors of estimate, to be regarded as serious counterevidence to the conclusion of successive independence. In Experiment 3, slopes of these functions were not quantified because there were too few conditions in each of two series. However it was clear that these slopes were not consistently different from zero either, and multiple regression analysis, which used data from all conditions in both series, supported the conclusion of successive independence. Across experiments, the successive independence found in Experiment 1 was thus confirmed in conditions in which the varied component arranged a high reinforcer total compared to the constant component (Experiment 2) and in which the varied component arranged a total that was usually higher, but one that varied as reinforcer ratios varied (Experiment 3).

Lobb and Davison (1977) also concluded that response allocation in a multiple-schedule component is independent of its successive reinforcement context (i.e., of the reinforcement conditions in a successively presented component). However, Lobb and Davison reached their conclusion on the observation that concurrent sensitivities during components were not different from those expected in regular concurrent schedules. That is, in Lobb and Davison's data, a ranged between .7 and 1.0. In the present experiments, concurrent sensitivities were lower than expected, and usually fell below the range reported as typical of concurrent variable-interval performance. Nevertheless, constant-component performances indicated that (whatever the reason for

Fig. 9. $\log_{10}$ concurrent response ratios (left panels) and $\log_{10}$ concurrent time ratios (right panels) for each of 3 pigeons in Experiment 3 for the varied component plotted as a function of $\log_{10}$ concurrent reinforcer ratios in the varied component. Equations of least-squares regression lines and standard errors of estimate (*SE*) are given for each bird. In each case, the origin is marked by a cross, and the vertical and horizontal scales are identical.

the low concurrent sensitivities) performance in a component is independent of reinforcement in the other component.

The present finding of successive independence is difficult to reconcile with the results of Nevin et al. (1978) from discrete-trials schedules. Nevin et al. arranged discrete-trials multiple-concurrent schedules in which reinforcers were arranged for responses on both

keys in a constant component and for responses on only one of two keys in the alternated varied component. Across conditions, two types of manipulation were used in the varied component. One manipulation involved shifting the location of the response-reinforcer contingency between the two keys over conditions, while keeping the rate of reinforcement constant. The second manipulation involved keep-

ing the location of the contingency constant but varying the rate of reinforcement in the varied component (thus changing the component reinforcer total). When the location of the varied-component contingency was changed, constant-component response allocation changed in the same direction, especially when there was an overall low rate of reinforcement in the constant component. In the present Experiments 1 and 2, changing the distribution of reinforcers between the two keys during the varied component (keeping the total reinforcers constant) produced no change in constant-component response allocation, even when the reinforcer total in that component was low relative to that in the varied component. When Nevin et al. varied the absolute reinforcer rate on only one key, response allocation changed in reverse directions in the two components—specifically, constant-component response allocation now favored the key with a lowered reinforcer rate in the varied component. The equivalent manipulation in the present Experiment 3 again produced no change in constant-component response allocation. Possibly, the difference in results arises from the use of discrete-trials versus free-operant schedules, or from the relatively short exposures to successive components in the study of Nevin et al. imposed by the use of discrete trials. Another possible explanation lies in the use of the infinite reinforcer ratios in Nevin et al.'s varied component (one alternative being extinction), compared with the finite ratios used here. For free-operant multiple-concurrent schedules, however, the present data provide convincing evidence in support of successive independence over a wide range of reinforcer ratios.

Multiple-Schedule Matching

The derivation of Equation 1 for multiple-schedule response ratios (McLean & White, 1983) from independent equations for absolute rate of responding in each multiple-schedule component assumed successive independence. McLean and White used multiple regression estimates of n from data obtained in several studies in support of that assumption. The data from the present experiments support Equation 1 by offering a stronger, more direct demonstration of successive independence than that afforded by multiple regression. In addition, the analyses of multiple-schedule data from these experiments support Equation 1 by con-

Table 5

Multiple regression estimates of a and n (Equation 2) for response and time ratios in Experiment 3. VACs are proportions of variance in obtained log ratios accounted for by predictions from Equation 4. Estimates were reached using data from all conditions (both series) for each bird.

Bird	a	n	VAC
Response ratios			
A2	.74	-.04	.97
A3	.60	.15	.85
A4	.61	-.09	.97
Time ratios			
A2	.80	.10	.94
A3	.62	.13	.94
A4	.69	-.06	.98

firmed two of its predictions based upon the total reinforcers obtained in the two components. In contrast to the usual result of lower sensitivity to reinforcement in multiple schedules than in concurrent schedules, Equation 1 predicts equal sensitivity in multiple schedules and concurrent schedules if the total reinforcers obtained in each component remain constant over conditions in multiple schedules. This prediction was confirmed in Experiments 1 and 2, which arranged constant reinforcer totals (summed across keys) in each component, and multiple sensitivity (m) was equal to the concurrent sensitivity (a) directly observed during the varied components.

The reinforcer totals in components approached constancy in some of the conditions arranged by McLean and White (1983), who used different rates of "analog R_0 " in two series of multiple-schedule conditions. With high, equal values for R_{O1} and R_{O2} , the ratio $(R_2^a + bR_{O2}^a)/(R_1^a + bR_{O1}^a)$ remains virtually constant when the multiple-schedule reinforcer ratio R_1/R_2 is varied, and Equation 1 predicts high multiple-schedule sensitivity. With low values for R_{O1} and R_{O2} , the same term varies as an inverse function of reinforcer ratio R_1/R_2 , and Equation 1 predicts lower multiple-schedule sensitivity. In McLean and White's study, sensitivity in multiple schedules was high when the analog values for R_{O1} and R_{O2} were large and equal by comparison with multiple-schedule sensitivities observed when these were small.

A second prediction from Equation 1 concerning multiple-schedule bias was also supported by these data. When the reinforcer to-

tals in components are constant over conditions but one total is consistently larger than the other, Equation 1 is equivalent to the generalized matching law for multiple schedules with $m = a$ (matching) and bias $q = (R_2^a + bR_{O2}^a)/(R_1^a + bR_{O1}^a)$. In Experiment 1, reinforcer totals were equal in the two components, so no bias was predicted for the multiple schedules. Obtained estimates for $\log q$ were close to zero for all subjects ($M = -.03$). In Experiment 2, reinforcer totals in Component 2 were large relative to those in Component 1, and Equation 1 therefore predicted the positive intercepts given in Figure 6.

Behavioral Contrast

The finding of successive independence in free-operant multiple-concurrent schedules may have important implications for accounts of absolute-rate behavioral contrast in regular multiple schedules. Equation 2 was originally proposed as an alternative to Herrnstein's (1970) account for behavioral contrast on the grounds that it is consistent with the assumption (see Herrnstein 1970, 1974) that the total behavioral output per unit of time, k , is constant.

In a multiple schedule, the term $P_1 + P_{O1}$ totals all behavior that occurs during Component 1. If the total behavioral output per unit time, k , is constant, then $P_1 + P_{O1}$ is constant, providing the component duration does not change. If responses P_1 , P_2 , P_{O1} , and P_{O2} are expressed as rates, (i.e., divided by the durations of their components) then $P_1 + P_{O1} = P_2 + P_{O2} = k$, regardless of the durations of components. Now if $P_1 + P_{O1} = k$, then an increase in constant-component responding P_1 , which follows a reduction in varied-component reinforcement R_2 (behavioral contrast), must be accompanied by an opposite change in P_{O1} . That is, the ratio P_1/P_{O1} must increase. Thus a change in allocation of behavior during constant components is an appropriate index of behavioral contrast. Indeed, if k is constant, behavioral contrast can be said to *comprise* such changes in behavior allocation. McLean and White (1983) showed that Herrnstein's own model for multiple-schedule performance is not consistent with this, because it does not predict an opposite change in P_{O1} when contrast is observed in the response rate P_1 . In addition, the change to varied-component reinforcement R_2 results in changes to the varied-component

reinforcer ratio, R_2/R_{O2} . This must be true unless variation to R_2 is accompanied by similar changes to R_{O2} . Several writers have suggested reasons why R_{O2} may undergo *opposite* changes but that would also result in reinforcer ratio changes during the varied component.

The successive independence found in these experiments suggests that the variations in constant-component response allocation that constitute behavioral contrast cannot arise from the direct influence of changes in the reinforcer ratio (R_2/R_{O2}) during the varied component. The provision of analog values for P_O and R_O in the present experiments yielded no evidence that behavior allocation (between whatever alternatives) in a component can be biased by relative reinforcer rate for those alternatives in another component. That is, if the changes in behavior allocation that constitute behavioral contrast during a constant component of a regular multiple schedule arise from the direct influence of changes to the reinforcer ratio in the varied component, then it should have been possible to demonstrate that influence using the explicitly programmed alternative responses arranged here. The failure to observe such successive dependence in the present multiple-concurrent schedules, despite attempts to optimize conditions for successive interaction, casts doubt on accounts of absolute-rate behavioral contrast that invoke direct interaction of components.

Alternative accounts of contrast effects in conventional multiple schedules, based on the reallocation of extraneous reinforcers between components, have been advanced by McLean and White (1983) and by Staddon (1982). McLean and White showed that such models for contrast need not invoke any direct influence of reinforcement in a varied component as the basis whereby extraneous reinforcers are reallocated to or from the constant component. The present finding of successive independence of multiple-schedule component performances therefore provides indirect support for these accounts.

CONCLUSION

To summarize, the present experiments consistently failed to produce changes in behavior allocation during a constant multiple-schedule component when the relative rate of reinforcement for the same response alterna-

tives was varied in another component. This invariance of constant-component behavior allocation was observed even under conditions of low overall reinforcement in the constant component and under conditions in which the total reinforcement in the varied component was both higher than that in the constant one and was varied over conditions. That is, the invariance persisted under conditions that have been shown to enhance component interactions in conventional multiple schedules. These data therefore support the assumption of successive independence of component performances, which is fundamental in the derivation of Equation 1, and suggest that accounts for absolute-rate behavioral contrast in multiple schedules should not entail direct interaction between components. Furthermore, analysis of multiple-schedule performances in these experiments provided direct support for Equation 1 by demonstrating equal sensitivity to reinforcement in multiple and concurrent schedules when component reinforcer totals remained at constant values over conditions, with multiple-schedule bias when those values were unequal.

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APPENDIX

Responses per minute on each key during S1 (P_{L1} and P_{R1}) and during S2 (P_{L2} and P_{R2}); proportions of available time in a component spent on the left key (T_{L1} and T_{L2}); and reinforcers per hour on each key in each component (R_{L1} , R_{L2} , R_{R1} , R_{R2}). Asterisks identify replications of conditions.

Bird	Con- dition	P_{L1}	P_{R1}	P_{L2}	P_{R2}	T_{L1}	T_{L2}	R_{L1}	R_{R1}	R_{L2}	R_{R2}
Experiment 1											
A1	1	27.8	81.0	56.9	60.3	.26	.50	22	148	80	81
	2	34.6	62.6	47.5	55.2	.35	.49	43	129	89	88
	2*	32.2	67.3	49.1	58.9	.30	.43	42	122	79	82
	3	39.6	70.1	43.2	72.8	.38	.43	58	98	75	90
	4	53.6	34.1	39.1	63.2	.67	.41	121	42	83	79
	5	68.9	28.6	43.3	65.8	.77	.45	153	22	82	86
A2	1	18.2	64.2	39.3	43.8	.20	.50	23	156	78	79
	2	25.7	52.7	40.1	38.9	.36	.57	43	126	91	70
	3	26.9	38.8	35.5	31.7	.48	.60	53	92	79	73
	4	46.5	26.2	44.2	43.8	.72	.57	120	41	78	78
	4*	49.4	27.0	41.1	38.8	.71	.55	115	38	80	82
	5	61.9	20.6	47.0	45.7	.80	.56	133	24	77	63
A3	1	25.6	115.9	41.5	112.1	.20	.37	22	158	84	87
	1*	50.8	62.9	63.3	76.3	.35	.44	20	145	80	82
	2	50.5	73.4	64.4	75.3	.42	.51	41	118	83	80
	3	48.6	70.6	53.2	65.8	.45	.50	60	102	82	78
	4	64.5	64.0	65.5	71.8	.63	.58	118	39	89	66
	5	71.9	53.6	65.0	87.0	.65	.47	149	19	82	83
A4	1	6.9	42.4	19.3	32.6	.16	.43	19	146	79	78
	2	12.1	39.5	23.4	32.0	.26	.51	41	116	71	83
	3	15.1	40.8	22.1	38.2	.30	.44	59	99	79	84
	4	30.1	25.3	21.2	38.8	.55	.43	119	39	82	50
	4*	29.8	23.5	28.1	39.2	.60	.51	121	43	85	90
	5	29.9	22.9	22.4	52.3	.61	.45	140	22	89	81
Experiment 2											
A1	1	35.4	41.8	92.5	25.9	.42	.73	22	43	166	21
	2	25.1	63.9	76.7	51.2	.39	.62	21	39	147	44
	3	25.1	40.7	76.5	53.0	.30	.58	23	39	119	62
	4	27.3	46.3	61.5	68.3	.31	.43	23	41	77	104
	5	25.9	58.1	40.6	91.8	.26	.32	20	41	58	129
	6	27.7	51.9	38.8	85.5	.33	.32	22	39	41	146
	7	24.0	55.3	21.2	89.7	.32	.19	20	43	23	156
	7*	26.0	48.7	31.7	84.2	.21	.22	21	44	23	157
A2	1	22.2	46.4	66.5	25.6	.37	.74	21	46	161	23
	2	18.8	38.3	58.9	27.3	.35	.69	18	41	146	35
	3	26.4	34.3	49.4	29.4	.50	.65	18	45	109	59
	3*	27.8	32.6	57.7	33.2	.55	.71	22	42	115	58
	4	22.1	36.2	44.4	49.9	.41	.51	22	42	102	78
	5	16.6	39.7	32.8	54.7	.33	.37	25	44	56	117
	6	24.2	47.8	29.5	69.7	.36	.31	23	49	44	155
	7	19.4	50.2	22.7	78.2	.32	.24	22	44	24	161
A3	1	44.0	57.4	116.6	22.2	.52	.85	22	42	166	17
	2	35.6	65.0	80.2	33.6	.39	.76	20	38	149	44
	3	57.3	85.5	82.7	68.1	.44	.64	22	43	123	62
	4	41.0	71.7	84.7	52.5	.41	.64	22	39	98	77
	5	62.2	78.9	70.9	82.6	.45	.49	23	45	58	118
	5*	39.4	77.3	48.2	88.2	.33	.38	23	46	60	120
	6	34.1	61.0	43.6	79.7	.31	.33	19	42	38	135
	7	50.6	65.4	46.8	90.6	.41	.33	24	43	23	160
A4	1	14.1	34.2	47.1	23.9	.29	.69	18	35	164	20
	2	15.2	37.1	35.9	27.0	.34	.63	20	41	146	41
	3	13.8	28.9	40.9	25.3	.39	.66	16	43	128	57

APPENDIX

(Continued)

Bird	Con- dition	P _{L1}	P _{R1}	P _{L2}	P _{R2}	T _{L1}	T _{L2}	R _{L1}	R _{R1}	R _{L2}	R _{R2}
A5	4	20.6	37.0	43.8	32.2	.40	.57	18	39	102	74
	4*	20.8	34.2	47.9	37.9	.35	.56	22	32	101	87
	5	15.8	38.4	27.4	46.7	.28	.40	20	40	62	117
	6	10.9	37.0	19.8	47.1	.25	.31	20	38	37	130
	7	22.1	38.2	24.4	69.4	.35	.25	20	46	22	158
	1	32.6	68.6	80.1	38.4	.39	.70	24	44	161	22
	2	29.0	49.6	93.9	39.4	.38	.74	23	40	152	41
	3	23.5	57.8	89.5	36.5	.28	.70	21	41	119	59
	4	24.8	60.4	27.1	84.1	.31	.30	19	47	83	108
	5	27.4	63.1	22.4	96.5	.33	.26	20	46	57	125
	6	36.3	79.3	26.9	116.6	.36	.22	24	48	43	164
	6*	25.6	67.1	36.0	105.4	.31	.28	18	41	42	138
	7	19.9	65.4	7.9	116.9	.29	.10	21	44	19	174
	A6	1	43.5	51.0	61.9	43.6	.46	.64	21	46	156
2		40.6	67.5	61.1	46.6	.40	.57	19	41	151	40
3		48.8	64.7	64.1	48.5	.45	.57	17	40	127	60
3*		34.6	51.1	54.9	37.7	.39	.60	22	38	113	61
4		48.1	72.9	56.5	58.6	.43	.51	24	43	85	102
5		41.0	71.5	41.5	60.5	.40	.43	18	43	58	118
6		38.3	49.1	45.2	52.4	.42	.46	22	36	39	116
7		41.3	61.6	35.8	62.2	.39	.32	23	42	21	168
Experiment 3											
A2	1	30.9	22.4	71.4	16.4	.62	.85	45	23	163	20
	2	34.0	20.5	47.4	22.9	.76	.74	41	23	44	20
	3	36.7	36.3	43.0	40.9	.54	.53	38	22	24	21
	4	20.1	54.4	48.0	50.2	.27	.49	41	137	162	142
	5	15.5	60.4	24.9	70.3	.21	.26	34	172	42	137
	6	16.5	60.1	18.6	70.2	.21	.22	35	140	23	147
A3	1	67.4	27.3	112.9	14.5	.65	.85	44	21	181	19
	2	63.5	39.5	83.5	35.2	.58	.67	40	22	41	20
	3	34.7	52.0	46.7	56.3	.45	.49	35	24	19	20
	3*	40.1	42.4	53.4	35.3	.53	.58	38	22	21	20
	4	35.2	45.7	69.4	48.7	.37	.53	37	138	160	147
	5	34.1	76.3	41.2	78.8	.26	.30	38	136	40	145
	6	23.6	84.7	24.2	85.9	.23	.22	43	149	21	156
	6*	30.7	61.2	29.3	75.1	.26	.22	40	144	28	160
A4	1	28.5	33.4	52.9	26.5	.46	.66	41	19	169	20
	2	29.6	37.3	39.1	39.0	.49	.51	38	20	42	20
	3	32.6	39.1	26.9	39.4	.47	.35	39	18	21	21
	4	8.0	35.3	26.4	32.8	.17	.42	35	145	148	135
	6	16.3	41.3	11.4	48.1	.22	.14	43	136	30	150