STIMULUS EFFECTS ON CONCURRENT PERFORMANCE IN TRANSITION

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Six experimentally naive pigeons were exposed to concurrent variable-interval variable-interval schedules in a three-key procedure in which food reinforcement followed pecks on the side keys and pecks on the center key served as changeover responses. In Phase 1, 3 birds were exposed to 20 combinations of five variable-interval values, with each variable-interval value consistently associated with a different color on the side keys. Another 3 pigeons were exposed to the same 20 conditions, but with a more standard procedure that used a nondifferential discriminative stimulus on the two side keys throughout all conditions. In Phase 2, the differential and nondifferential stimulus conditions were reversed for each pigeon. Each condition lasted for one 5-hr session and one subsequent 1-hr session. In the last 14 conditions of each phase, the presence of differential discriminative stimuli decreased the time necessary for differential responding to develop and increased the sensitivity of behavior to reinforcement distribution in the 1st hr of training; during the last hours of training in each condition, however, the effects of the differential discriminative stimuli could not be distinguished from the effects of reinforcement distribution per se. These results show the importance of studying transitions in behavior as well as final performance. They may also be relevant to discrepancies in the results of previous experiments that have used nonhuman and human subjects.
Key words: choice, stimulus control, reinforcement rate, concurrent schedules, discrimination, generalized matching equation, key peck, pigeons

Ferster and Skinner (1957) defined concurrent operants as "two or more responses, of different topography at least with respect to locus, capable of being executed with little mutual interference at the same time or in rapid alternation, under the control of separate programming devices, e.g., responses to two keys present at the same time under separate schedules" (p. 724). Findley (1958) expanded the definition by showing that responses of the same topography, occurring on the same response key, are different operants if different key colors are associated with different reinforcement schedules. Both definitions clearly point to the fact that in concurrent schedules each operant is part of a contingency involving discriminative stimuli (locus, color, etc.), responses, and consequences for responding.

Catania (1966), in the first research review of concurrent schedules, pointed out the importance of discriminative stimuli in determining concurrent performance. Rilling (1977) noted that concurrent schedules should be considered as one of the discriminative training procedures; that is, these schedules yield differential behavior in simultaneously and independently programmed alternatives that are correlated with different discriminative stimuli. However, research on concurrent schedules since Herrnstein's (1970) seminal paper has been dominated by studies of response-reinforcement relationships. In the 1970s, relatively few studies on the role of discriminative stimuli were reported (but see Beale & Winton, 1970; Blough, 1973; Catania, Silverman, & Stubbs, 1974; Honig, Beale, Seraganian, Lander, & Muir, 1972; Winton & Beale, 1971).

In the 1980s, two lines of research on the discriminative control of concurrent performances began to evolve. One line of research brought together the fields of concurrent schedules and signal detection, and can be traced to Nevin (1969) and a paper presented by Nevin and his associates at the 1977 Psychonomic Society meeting that was formally published 5 years later (Nevin, Jenkins, Whittaker, & Yarensky, 1982). At this time, Davison and

Tustin (1978) initiated a long sequence of reports on the relation between concurrent performance and signal-detection theory (Boldero, Davison, & McCarthy, 1985; Davison & Jenkins, 1985; Davison & McCarthy, 1980; Davison, McCarthy, & Jensen, 1985; McCarthy, 1983; McCarthy & Davison, 1979, 1980, 1981, 1982, 1984; McCarthy, Davison, & Jenkins, 1982; Nevin, 1981a, 1981b; for review see Davison & McCarthy, 1988).

A second line of research began with Bourland and Miller (1978), who initiated a sequence of experiments on the role of discriminative stimuli as codeterminants of behavior allocation (Bourland & Miller, 1981; Miller, Saunders, & Bourland, 1980; Takahashi & Iwamoto, 1986). In this line of research, concurrent responding provides data on the role of discriminative stimuli in the determination of the exponent in Baum's (1974) generalized matching law. When variable-interval (VI) schedules are programmed in both concurrent alternatives, Baum's equation describes the relationship between response and reinforcement distributions in steady state:

$$T_1/T_2 \text{ or } B_1/B_2 = k(R_1/R_2)^a, \quad (1)$$

or, in the logarithmic form, as it is most frequently used,

$$\log(B_1/B_2) = \log k + a \log(R_1/R_2), \quad (2)$$

where T, B, and R refer to time allocation, frequencies of responding, and frequencies of reinforcement, respectively, a and k are empirical constants, and subscripts identify schedules of the concurrent pair. The parameter k measures bias towards one alternative, and the exponent a is interpreted as a measure of the sensitivity of behavior to variations in reinforcement distribution (Baum, 1974). Bourland and Miller (1981) and Miller et al. (1980) showed that differences in exponent a of the functions associated with different schedules revealed the contributions of the exteroceptive stimuli to the discriminability of the different reinforcement rates in the concurrent components, confirming a suggestion previously advanced by Baum (1979; see also Nevin, 1981b). Using a changeover-key procedure (Findley, 1958), Miller and colleagues programmed independent and simultaneous VI schedules with different rates of reinforcement. Similar versus different line orientations (Miller et al., 1980) or identical versus different colors (Bourland & Miller, 1981) were used on the single main key to signal the two-component schedules. When the stimuli associated with each component were identical ("parallel schedules"), changeover responses alternated only the operative reinforcement schedule. Higher values of a were found when different exteroceptive stimuli signaled the two-component schedules. These results show the importance of different stimuli correlated with each schedule in one concurrent condition in the determination of the behavioral sensitivity to reinforcement rates.

In studies of concurrent schedules with non-humans, including those by Miller and colleagues, different stimuli have been correlated with the components of the concurrent schedules during one experimental condition but have not been varied from one condition to the next when the components have been changed. Across conditions of the experiment, the same color or locus might be associated with a variety of reinforcement rates. Results have shown that the stimulus differences (color, locus, etc.) in each condition, together with the different reinforcement rates, are enough to produce differential behavior in the alternatives of one concurrent condition, as well as from one condition to the next. With standard concurrent procedures, Equation 2 is a reasonably accurate description of the results when behavior in steady state is analyzed (de Villiers, 1977). Studies of the effects on choice of correlating in this way the same exteroceptive stimuli with several reinforcement rates have been neglected, although, as Mackintosh (1977) has pointed out, ". . . there is evidence that prior exposure to a particular correlation between a stimulus and a reinforcer may affect the control over responding acquired by that stimulus during subsequent experimental training" (p. 488). The purpose of the present experiment was to extend the findings of Bourland and Miller (1981) and Miller et al. (1980) on the role of discriminative stimuli as determinants of pigeons' behavior in concurrent schedules, but with different stimuli consistently associated with different reinforcement rates across experimental conditions.

Concurrent procedures that incorporate different discriminative stimuli, each associated with different values of the VI schedules, have been used in some studies with human subjects (Bradshaw, Ruddle, & Szabadi, 1981; Bradshaw, Szabadi, & Bevan, 1976, 1979; Brad-

shaw, Szabadi, Bevan, & Ruddle, 1979; Lowe & Horne, 1985; Ruddle, Bradshaw, & Szabadi, 1981; Ruddle, Bradshaw, Szabadi, & Bevan, 1979; Ruddle, Bradshaw, Szabadi, & Foster, 1982; Takahashi & Iwamoto, 1986). The data obtained by Bradshaw and associates show a conformity to concurrent performance data for nonhumans reported in the literature. However, studies with human subjects that have used the more traditional procedure with fixed discriminative stimuli have found extremely low values of exponent *a*, or even negative values (Navarick & Chellsen, 1983; Oscar-Berman, Heyman, Bonner, & Ryder, 1980; Pierce, Epling, & Greer, 1981; Poppen, 1982; Schmitt, 1974). Lowe and Horne (1985) and Takahashi and Iwamoto (1986) have shown that differential discriminative stimuli are important determinants of human performance that conforms to the matching equation.

The present experiment, therefore, assessed the effects on choice behavior in animals of differential or nondifferential discriminative stimuli associated with different reinforcement rates. It incorporated a procedure described by Todorov, Hanna, and Bittencourt de Sá (1984), which employs a single long experimental session in each condition. This procedure has been found to produce data comparable to those obtained with standard procedures that involve many more experimental hours in each experimental condition. It was hoped that the long sessions in the present experiment would also provide opportunities for studying within sessions the transitions resulting from changes in the experimental conditions. The present experiment also incorporated one subsequent, and more conventional, 1-hr session in each condition; this was designed to provide a check for any effects of satiation and/or fatigue on performance towards the end of the long sessions, and thus to provide a further evaluation of the usefulness of the procedure first reported by Todorov et al. (1984).

METHOD

Subjects

Six experimentally naive white pigeons served as subjects. The birds were maintained at approximately 80% of their free-feeding body weights by additional feeding, when necessary, after the conclusion of each experimental session.

Apparatus

Three three-response-key versions of standard experimental chambers for operant-conditioning studies with pigeons (Campden Instruments) were used. Colors on each key were obtained by illumination of the keys through colored filters by a 2-W bulb. An exhaust fan provided masking noise. The experiment was controlled and the data recorded by an on-line microcomputer (Acorn®) programmed in ONLIBASIC.

Procedure

The birds were trained to feed from the magazine and then were trained to peck each of the three keys illuminated white by reinforcing successive approximations to the final response. Subjects were then transferred to concurrent VI 15-s VI 15-s schedules (*conc* VI 15 s VI 15 s) with a three-key procedure (Todorov, Acuña-Santaella, & Falcon-Sanguinetti, 1982) also with all three keys illuminated white. The middle key (changeover key), one of the side keys (main keys), and the houselight remained lit throughout the session, except during reinforcement periods. Pecks on the middle key switched the operative and lit side key. Pecks on the lit side key might produce reinforcement (3-s access to mixed grains). During reinforcement periods, only the hopper was illuminated. This preliminary training lasted for two sessions of 60 reinforcements each. To prevent exclusive preference from developing, during the first half of the first session, if five successive reinforcements were delivered after pecks on only one main key, extinction was programmed for that key for the next five reinforcements.

Subjects were then divided into two groups. Reinforcement rates were varied in 20 experimental conditions using combinations of five different values of VI schedules (Table 1) with the three-key concurrent procedure as described above. The sequence of the conditions was random except that the same VI schedule was not presented in more than two consecutive conditions and the main key allocated with the highest frequency of reinforcement was balanced between conditions (Silberberg & Fantino, 1970). Table 1 shows the programmed rate of reinforcement of each component of the concurrent pairs and the sequence of presentation of the experimental

conditions. Group 1 (P1, P6, and P8) was exposed to these 20 conditions of *conc* VI VI with a different key color associated with each component VI schedule. The VI 72 s (50 reinforcers per hour) was always associated with green, VI 90 s (40 reinforcers per hour) with yellow, VI 120 s (30 reinforcers per hour) with blue, VI 180 s (20 reinforcers per hour) with purple, and VI 360 s (10 reinforcers per hour) with red (different-color phase). The changeover key was illuminated by a white light. Group 2 (P2, P3, and P10) was exposed to the same 20 pairs of VI schedules, except that each main key was pink regardless of the VI schedule in operation (same-color phase).

A 3-s changeover delay (COD; Herrnstein, 1961) was in effect after each switching response on the central key (i.e., programmed reinforcement was not delivered until a key peck occurred at least 3 s after a changeover response). Each condition lasted for one 5-hr session (long-session procedure; Todorov, Ferrara, Gurgel-Azzi, & Oliveira-Castro, 1982[1]; Todorov et al., 1984) and one 1-hr session, with 1 nonexperimental day between these sessions. The number of responses on each key and the number of reinforcements were recorded at the end of each hour of the session.

A short stimulus-control test was then conducted in extinction on 2 consecutive days. This test consisted of 15-s presentations on the side keys of each of the five different colors used in the different-color phase for Group 1 (green, yellow, blue, purple, and red) and the color used in the same-color phase for Group 2 (pink), separated by 2 s of timeout. The six colors were presented, one at a time, 12 times in succession in a random sequence. Because of limitations of the equipment, the colors could not be randomly assigned to the two side keys: Green, blue, and red were presented on the right key on the 1st day of testing and on the left key on the 2nd day, in order to control for key bias; yellow, purple, and pink were presented on the right key on the 1st day of testing and on the left key on the 2nd day. The houselight remained on throughout test sessions. The number of responses to each color was recorded

Table 1

Programmed rates of reinforcement for the components of the concurrent schedules in each experimental condition. The first six conditions were considered to be preliminary training, and the results obtained from these conditions are not included in the data analyses.

	Reinforcers per hour	
Condition	Left	Right
1	50	50
2	10	40
3	40	20
4	30	50
5	20	10
6	30	30
7	10	50
8	20	20
9	50	40
10	20	30
11	30	10
12	40	40
13	40	30
14	10	10
15	50	20
16	30	50
17	40	20
18	10	40
19	50	10
20	20	30

at the end of each test session. Each session lasted approximately 20 min.

After the stimulus-control tests, the animals in Group 1 were exposed to the same sequence of 20 experimental conditions in concurrent schedules as before (Table 1), but both side keys were pink regardless of the VI schedule in operation (same-color phase). The animals in Group 2 were also exposed to the same 20 conditions as before, but now with the different key colors differentially associated with each component VI schedule (different-color phase).

The experiment concluded with two further test sessions of stimulus control as described above.

RESULTS

In the first six conditions (see Table 1) each stimulus and schedule was presented at least once on each main key in a variety of concurrent schedules. The results obtained from this preliminary training in each experimental phase were not used in the data analyses. All figures presented below show on the left the results for the individual subjects of Group 1

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[1] Todorov, J. C., Ferrara, M. L. D., Gurgel-Azzi, R., & Oliveira-Castro, J. M. (1982, July). *Desempenhos concorrentes: Um estudo descritivo em sessões de longa duração.* Paper presented at the Meeting of the Sociedade Brasileira para o Progresso da Ciência (Brazil).
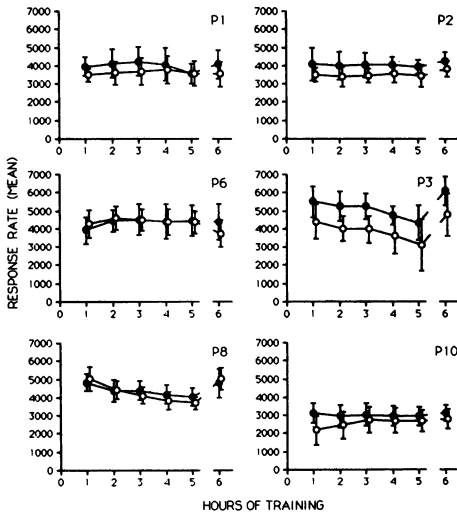
Fig. 1. Rate of responding on the main keys (total number of responses on the side keys per hour) during each hour of the 5-hr session and subsequent 1-hr session (6th hr of training). Average data of the last 14 different-color conditions are plotted with filled symbols, and average data of the last 14 same-color conditions are plotted with unfilled symbols for individual subjects. Vertical bars indicate the standard deviation of the mean.
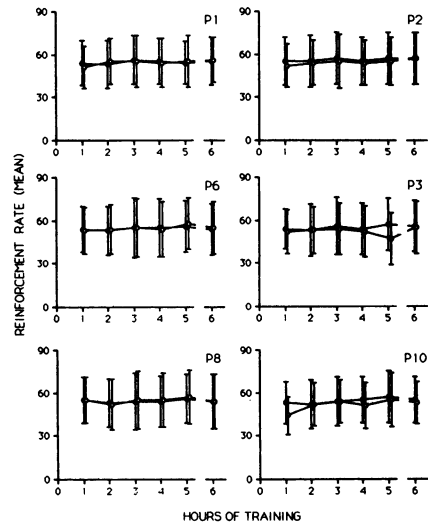
Fig. 2. Overall obtained reinforcements during each hour of the 5-hr session and subsequent 1-hr session (6th hr of training). Average data of the last 14 different-color conditions are plotted with filled symbols, and average data of the last 14 same-color conditions are plotted with unfilled symbols for individual subjects. Vertical bars indicate the standard deviation of the mean.

(P1, P6, and P8) and on the right the results for Group 2 (P2, P3, and P10). Group 1 was exposed to the different-color conditions before the same-color conditions. For Group 2 this order was reversed.

Figures 1, 2, and 3 show how responses and reinforcements varied during the long and short sessions for each experimental phase. Overall response rates on the two main keys (responses on the side keys per hour) as a function of hours of training in the last 14 conditions of each experimental phase are shown in Figure 1. Average data and respective standard deviations of individual subjects of Groups 1 and 2 are presented separately. In general, responding on the side keys was sustained at high rates during the 5-hr session as well as during the 1-hr session. Three subjects (P1, P3, and P8), however, showed some decrease in response rate during the long session and an increase in the short session (6th hr of training). Furthermore, response rates on the main keys during the different-color phase were higher than during the same-color phase, especially for subjects of Group 2, which were exposed to the different-color phase after the same-color phase. The obtained rate of reinforcers during training, however, did not vary

in the different experimental phases, throughout the long session, and from the long session to the short session (Figure 2).
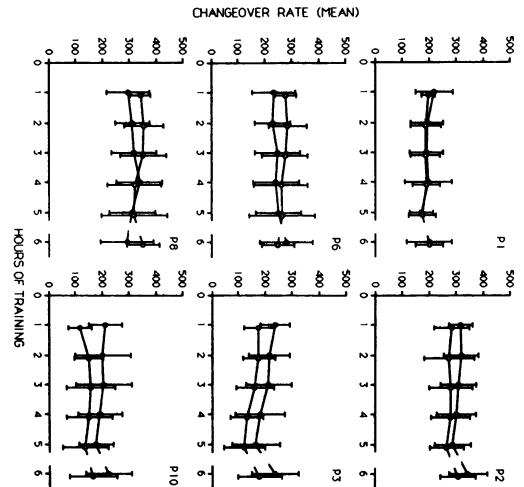
CHANGEOVER RATE (MEAN)

Fig. 3. Changeover responses per hour during each hour of the 5-hr session and subsequent 1-hr session (6th hr of training). Average data of the last 14 different-color conditions are plotted with filled symbols, and average data of the last 14 same-color conditions are plotted with unfilled symbols for individual subjects. Vertical bars indicate the standard deviation of the mean.

Figure 3 shows changeover rates (responses on the central key per hour) as a function of the hours of training in the last 14 conditions of each experimental phase. Average data and respective standard deviations for each subject are presented separately. Although there is some evidence that changeover response rates decreased during the 5-hr sessions, they remained high in the last hour. Subjects of Group 2 (P2, P3, and P10) showed consistently more changeover responses during the different-color phase than in the preceding same-color phase. (Tables that show the number of responses, reinforcers, and changeovers for each subject during the 1st, 4th, and 6th hr of training in the last 14 conditions of each experimental phase are available from the first author.)

Overall response rates on each of the five VI schedules used in the last 14 conditions of each experimental phase are shown in Figures 4, 5, and 6. These data are the average rates on each VI schedule, derived from the rates on that schedule in combination with other VI schedules, as outlined in Table 1. Data are presented for each pigeon separately for the 1st (Figure 4), 4th (Figure 5), and 6th (Figure 6) hr of training. All birds of both groups showed increasing response rates as a function
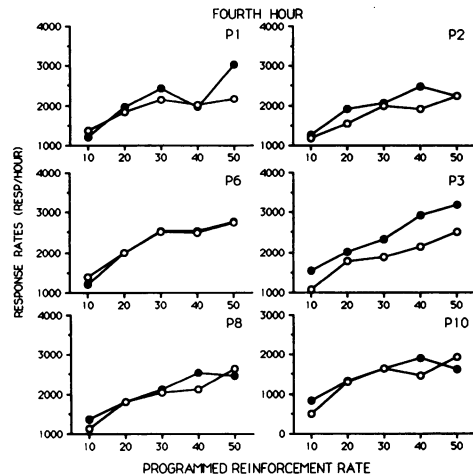
Fig. 5. Response rates (mean) as a function of reinforcement rates programmed by each VI schedule used in the last 14 conditions of the different-color phase (filled symbols) and of the same-color phase (unfilled symbols) during the 4th hr of training. P1, P6, and P8 (Group 1) were exposed to the different-color phase first: P2, P3, and P10 (Group 2) were exposed to the same-color phase first.

of the programmed reinforcement rates in the different-color phase during the 3 analyzed hours. Similar differential behavior can be seen during the 4th and 6th hr of the same-color
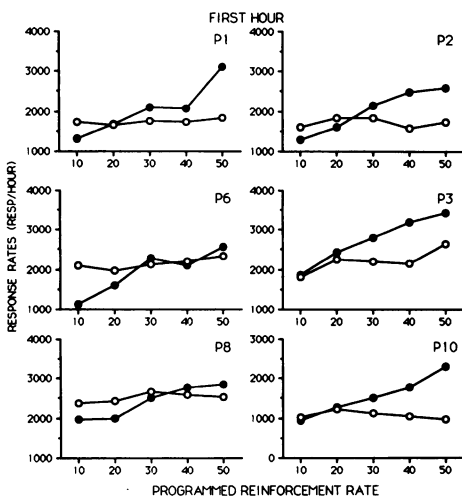
Fig. 4. Response rates (mean) as a function of reinforcement rates programmed by each VI schedule used in the last 14 conditions of the different-color phase (filled symbols) and of the same-color phase (unfilled symbols) during the 1st hr of training. P1, P6, and P8 (Group 1) were exposed to the different-color phase first; P2, P3, and P10 (Group 2) were exposed to the same-color phase first.

Fig. 6. Response rates (mean) as a function of reinforcement rates programmed by each VI schedule used in the last 14 conditions of the different-color phase (filled symbols) and of the same-color phase (unfilled symbols) during the 6th hr of training (second session). P1, P6, and P8 (Group 1) were exposed to the different-color phase first; P2, P3, and P10 (Group 2) were exposed to the same-color phase first.
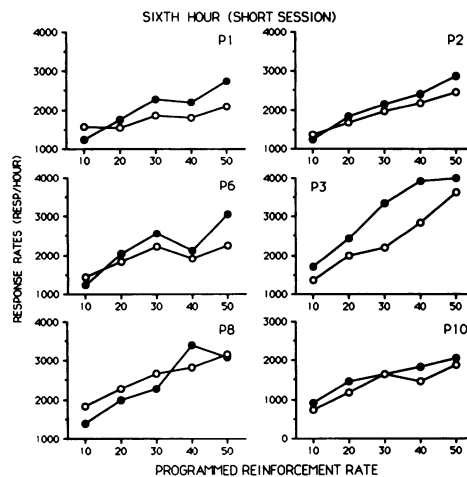
Table 2

Coefficient of determination (r^2), constant (k), and standard error of estimation (SE) values for each hour of training, computed by the least squares method for the last 14 conditions of the different-color (DC) and same-color (SC) phases.

		r^2		k		SE	
Subject	Hour	DC	SC	DC	SC	DC	SC
P1	1	0.76	0.01*	1.00	1.35	0.23	0.10
	2	0.92	0.78	1.00	1.29	0.10	0.12
	3	0.92	0.81	1.10	1.35	0.11	0.10
	4	0.91	0.89	1.12	1.38	0.11	0.06
	5	0.88	0.88	1.05	1.32	0.12	0.08
	6	0.92	0.88	1.23	1.23	0.10	0.07
P6	1	0.79	0.42*	1.17	1.02	0.18	0.19
	2	0.88	0.85	1.07	0.90	0.11	0.08
	3	0.98	0.93	0.99	0.94	0.05	0.08
	4	0.94	0.95	0.93	0.91	0.09	0.08
	5	0.98	0.95	1.01	0.93	0.05	0.09
	6	0.94	0.84	1.16	0.97	0.10	0.10
P8	1	0.57	0.01*	0.69	0.74	0.19	0.13
	2	0.65	0.87	0.69	0.74	0.25	0.10
	3	0.82	0.87	0.66	0.79	0.13	0.11
	4	0.84	0.86	0.70	0.71	0.13	0.14
	5	0.90	0.93	0.80	0.81	0.11	0.10
	6	0.89	0.84	0.75	0.81	0.15	0.12
P2[a]	1	0.79	0.34*	0.79	0.62	0.17	0.15
	2	0.89	0.87	0.72	0.56	0.14	0.13
	3	0.79	0.74	0.69	0.52	0.15	0.17
	4	0.85	0.68	0.74	0.58	0.15	0.25
	5	0.80	0.89	0.74	0.51	0.15	0.13
	6	0.86	0.86	0.89	0.59	0.15	0.10
P3[a]	1	0.85	0.30*	0.98	1.17	0.13	0.27
	2	0.87	0.88	1.15	1.32	0.12	0.12
	3	0.86	0.91	1.15	1.29	0.13	0.11
	4	0.92	0.91	1.10	1.26	0.13	0.12
	5	0.89	0.91	1.23	1.41	0.15	0.11
	6	0.95	0.94	1.12	1.32	0.10	0.10
P10[a]	1	0.95	0.05*	1.15	2.24	0.10	0.47
	2	0.92	0.83	0.99	1.35	0.15	0.17
	3	0.90	0.95	0.87	1.48	0.16	0.12
	4	0.85	0.86	0.85	1.38	0.18	0.28
	5	0.86	0.92	0.78	1.26	0.16	0.23
	6	0.90	0.91	0.95	1.38	0.13	0.19

* $p > .01$.
[a] Same-color phase first.

phase, but during the 1st hr the curves were flat.

Table 2 and Figure 7 show results of the linear regression analysis using the least squares method. Coefficients of determination (r^2), values of the constant (k), and standard errors of the estimations for each hour of training in the last 14 experimental conditions of each phase are shown in Table 2. The second 1-hr session of each condition is shown as the 6th hr of training. In the 1st hr of training in the different-color phase, the proportions of variation accounted for by Equation 2 (r^2) were larger than .75 in 5 of the 6 birds. The values of r^2 in the 1st hr of exposure to the same-color phase were low (smaller than .50) and not statistically significant ($p > .01$) for all birds, including those from Group 1, which had already been exposed to those pairs of concurrent VI schedules in the different-color phase. In the 2nd hr of training, proportions of variation accounted for by Equation 2 for all 6 birds in the same-color phase were larger than .70 (except P8) and did not differ systematically from those in the different-color phase. Furthermore, r^2 values for the second session were close to those of the last hours of the first session.

Table 2 also shows values of the constant k (Equation 2) for each hour of training in the last 14 conditions of each experimental phase. In general, values of k were close to 1.0 and did not vary systematically as a function of hours of training in all 6 birds. Subjects P6 and P8 showed similar k values in both experimental phases. However P1 and all 3 subjects exposed to the same-color phase first (P2, P3, and P10) showed consistently greater bias toward one main key (k values differing from 1.0) during conditions of the same-color phase than during those of the different-color phase.

Figure 7 shows, separately for each pigeon, the values of the exponent a (Equation 2) as a function of hours of training in the last 14 conditions of each experimental phase. The sensitivity of response distribution to the distribution of reinforcers (values of a) increased as a function of hours of training in the conditions of the same-color phase but did not vary systematically in the different-color phase (except P3). All 6 birds showed high sensitivity to reinforcement distribution ($a > .70$) in the 1st hr of training in the different-color phase. Exponent values for all 6 subjects were higher in the different-color phase than in the same-color phase in the first 2 hr. Differences between the same-color and different-color phases became unsystematic in the 3rd hr. Sensitivity to reinforcement decreased in the second session (6th hr) for 5 of the 6 birds when exposed to the same-color conditions.

Figure 8 shows the results of the stimulus-control tests. Relative frequencies of responses
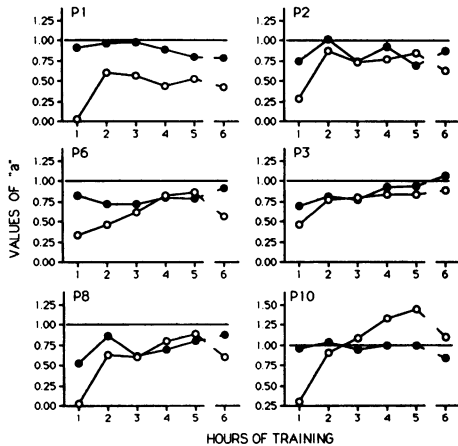
Fig. 7. Values of a (Equation 2) as a function of hours of training in the last 14 conditions of the different-color phase (filled symbols) and of the same-color phase (unfilled symbols). The second session is presented as the 6th hr of training. P1, P6, and P8 (Group 1) were exposed to the different-color phase first; P2, P3, and P10 (Group 2) were exposed to the same-color phase first.

on colors (response frequency in the two test sessions in each color divided by the highest response frequency) were plotted in increasing order of the reinforcement rates that had been correlated with the different colors. Different curves depict relative stimulus-control gradients after the same-color phase and after the different-color phase. Data from each bird are presented separately. The birds exposed first to the different-color phase (left side of Figure 8) showed increasing frequencies of responding in colors associated with higher frequencies of reinforcement, and in both tests of stimulus control a peak of responding occurred when keys were illuminated green or yellow. With 2 birds (P1 and P6), there were higher relative frequencies of responding in pink after the same-color phase than after the different-color phase. With subjects exposed to the same-color phase first (right side of Figure 8), the test after the same-color phase showed the highest frequency of responding to pink. Colors that had not yet been presented to these subjects in the experimental situation exerted no consistent effects, with relatively few or no responses on green, yellow, and red. Curves related to tests after the subsequent different-color phase showed increasing frequency of responding in colors that had been associated with higher frequencies of reinforcement, with the highest frequency in green (P2 and P10) or yellow

(P3). The relative frequency in pink decreased substantially in comparison with the tests after the same-color phase for these 3 pigeons.

DISCUSSION

The results of this experiment show that the rate of responses on the side keys, the obtained reinforcement frequency, and the rate of changeover responses did not differ greatly throughout the 5-hr sessions, and they did not change markedly from the last hours of the long session to the subsequent 1-hr session (Figures 1, 2, and 3). Some subjects showed a small decrease in response rates throughout the continuous 5 hr of training in both conditions, but these rates were still high in the 5th hr. There was some evidence that the different-color phase produced higher rates of responding than the same-color phase did (see Figure 1, P1, P2, P3, and P10).

Response rates (average) on each color/VI schedule during the 1st hr of training increased with the reinforcement rates programmed by the schedule when different stimuli signaled each VI, but they did not change systematically during conditions that were signaled by the nondifferential stimulus (Figure 4). During the 4th and 6th hr, however, differentiation of behavior in the color/VI schedules occurred whether or not different discriminative stimuli were used (Figures 5 and 6).

The matching equation proved to be a good description of the relationship between distribution of responses and distribution of reinforcements (Table 2 and Figure 7). Variances accounted for by Equation 2 in the 2nd hr of training were higher than 70% for all subjects (except P8, 2nd hr). During the 1st hr, however, although the results of the different-color phase were well described by Equation 2 ($r^2 > 0.57$), the results from the same-color phase were not statistically significant ($p \geq .01$). Bias (value of k) did not vary systematically during training in both experimental phases. The sensitivity of behavior to reinforcement distribution (value of a) increased with hours of training in the same-color phase but remained high (range, 0.5 to 1.10) in all hours of training in the different-color phase.

Stimulus-control tests showed that orderly differential behavior on the different colors occurred only after training in the different-color phase (Figure 8).
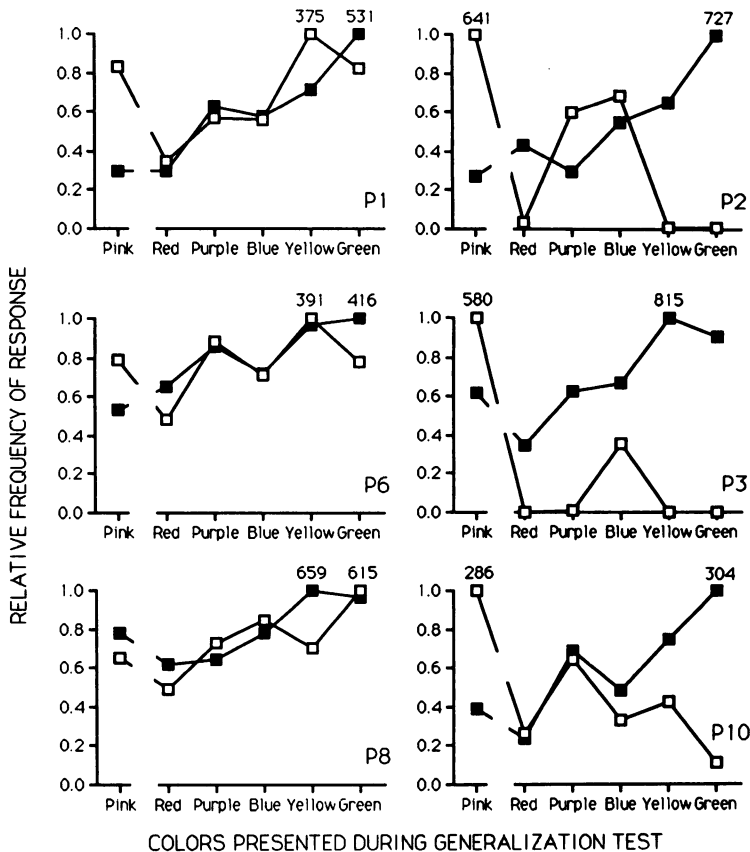
Fig. 8. Relative frequency of responding on each color (number of responses on the color divided by the highest frequency) in the stimulus-control test after exposure to the different-color phase (filled symbols) and after exposure to the same-color phase (unfilled symbols). The number of responses in the color that produced most responses is shown above the relevant data point. Colors are organized in decreasing order of correlated reinforcement rate, except for pink (the color used during same-color conditions). P1, P6, and P8 (Group 1) were exposed to the different-color phase first; P2, P3, and P10 (Group 2) were exposed to the same-color phase first.

The present experiment therefore provides further evidence that discriminative stimuli play a significant role in performance on simultaneously available reinforcement schedules. When color stimuli were differentially associated with reinforcement rates of the component schedules in a series of concurrent schedules (different-color phase), differential behavior typical of steady-state occurred in the 1st hr of exposure to new combinations of these component schedules. Even in the 1st hr of training in the conditions with differential discriminative stimuli, (a) there was a significant relationship between response and reinforcement distribution, with variances accounted for by Equation 2 greater than .70 (Table 2), (b) there were differential overall response rates on each color and schedule (Figure 4), and (c)

high values of the exponent a were obtained (i.e., high sensitivity to reinforcement distribution), and these values were close to those found in the last hours of training (Figure 7). After the 3rd hr of continuous training, however, behavior measures in conditions signaled with different colors could not be distinguished from behavior measured in conditions signaled with no different colors. Therefore, when the subjects' behavior had made contact with the reinforcement contingencies, effects of differential discriminative stimuli could no longer be distinguished from the effects of reinforcement distribution per se and from other cues (i.e., key location) provided by the concurrent schedules.

The data confirm the adequacy of the procedure in which each experimental condition

is in effect for only one session of long duration (Todorov et al., 1984). Variances accounted for by Equation 2 (r^2) and values of exponent *a* in the last hours of training were within the range reported from earlier experiments (Baum, 1979; de Villiers, 1977; Myers & Myers, 1977; Taylor & Davison, 1983; Todorov, Oliveira-Castro, Hanna, Bittencourt de Sá, & Barreto, 1983; Wearden & Burgess, 1982). Therefore, the procedure produced within one long session data comparable to stable behavior from studies that used many short sessions. The procedure also made it possible to detect within an experimental session the effects of changed schedule and stimulus conditions. Furthermore, this study extended the results from Todorov et al. (1984) to naive subjects when preliminary training is part of the experimental design. It also shows that exponent values, overall response rates on the main keys, and changeover rates were not greatly affected by satiation or fatigue in these long sessions, in that response and reinforcement rates did not change greatly throughout the 5-hr session (Figures 1, 2, and 3); behavior measures and obtained reinforcers in the second short session, in general, were close to those found in the last hours of the long session.

The results of the present study show the importance of studying transitions in behavior as well as final performance, because some variables (here discriminative stimuli) may have differential effects only early in a procedure. It is important to note that the standard procedure of analyzing stable data after a number of short sessions would misleadingly provide negative results of the experimental manipulations used in this study.

The present experiment confirms and extends previous findings (Bourland & Miller, 1981; Miller et al., 1980) that differences in the external cues associated with reinforcement schedules increase the sensitivity of behavior to changes in reinforcement distribution. Bourland and Miller (1981) and Miller et al. (1980), however, presented only steady-state data derived from the Findley two-key procedure. The present experiment extends these findings to behavior in transition using a three-key procedure. Exponent values from Equation 2 were greater in the first hours of training in the conditions in which colors were differentially associated with reinforcement rates than in those in which the same color

was associated with all reinforcement rates of the component schedules. Exponent values did not differ systematically after the first hours of training. Note that differential spatial cues for each component of the concurrent schedules (as there are in the three-key procedure) and the different densities of reinforcement in each schedule proved to be sufficient to produce differential behavior, so it is not perhaps surprising that no orderly differences were found in the last hours of training as a function of differential colors. Further, the correlation between values of exponent *a* and the degree (steepness) of differential response rates on the colors and programmed reinforcement rates, which is suggested when Figure 7 is compared with Figures 4 to 6, confirms that the exponent *a* reveals the contributions of the exteroceptive stimuli to the discriminability of the different reinforcement rates (Baum, 1974; Bourland & Miller, 1981; Miller et al., 1980). Therefore, the matching equation proved to be a useful analytic tool in the present experiment.

Stimulus-control effects were reliable in that they were seen in three different behavior measures: (a) response rates on each color and schedule, (b) exponent values, and (c) stimulus-control gradients. Analysis of response rates on each color and schedule showed the effects of the exteroceptive stimuli on the relation between absolute responses and programmed reinforcements regardless of the concurrent pair of the schedule. Analysis of the exponent values showed the effects of the exteroceptive stimuli on the interaction between relative responding and relative reinforcement rates. Both measures show the contribution of stimuli in the control of concurrent performances. Stimulus-control gradients showed the control subsequently exerted by the stimuli on responding when there were no reinforcing consequences (i.e., the effects of previous training in concurrent schedules). Note that the results for those subjects exposed to the different-color conditions first showed similar gradients taken after both experimental phases (Figure 8); therefore, stimulus control was still evident after prolonged exposure to same-color conditions with these pigeons.

The present experiment provides further evidence that the generalized matching equation describes reasonably well the relationship between choice behavior and reinforcement rates in studies with pigeons. However, results of

studies with human subjects that have used a procedure similar to the different-color phase in the present study have not always been well described by Equation 2. The present results may cast some light on these discrepancies. The results of the different-color phase showed that the differential discriminative stimuli played a major role in the development of schedule-controlled choice behavior. However, generalized matching has not successfully described transitional choice behavior of pigeons when (a) only short sessions are used and data from the first sessions are analyzed (e.g., Todorov et al., 1983) and (b) long sessions and same-color conditions are used and data from the 1st hr of training are analyzed (Todorov et al., 1984; the present study). Pigeons are usually trained for an extended number of sessions in each condition, and data from the last sessions in the conditions have been reported to conform with Equation 2. Human subjects are usually exposed to a number of conditions for a relatively short period of time. Although it could be argued that in both cases stability criteria have been used, the criteria in studies with human subjects have often been comparisons between parts of sessions from the first days of training. This is not the usual procedure with nonhuman subjects, and there is no empirical evidence that humans require less training in concurrent schedules. Thus, the use of differential discriminative stimuli with humans would be expected to make a significant contribution to sensitivity (a) as it did in this study during the 1st hr of training. Some evidence that discriminative stimuli play an important role in human choice has already been reported (Lowe & Horne, 1985; Takahashi & Iwamoto, 1986). Perhaps for practical reasons, however, the effects of the length of training in concurrent schedules have not yet been investigated in human choice.

With the increase in the number of studies of human behavior during the 1980s, discrepancies in results from human and nonhuman subjects have often been attributed to more complex determinants of behavior, such as the verbal rules that only humans sometimes formulate for themselves (e.g., Logue, Peña-Correal, Rodriguez, & Kabela, 1986; Lowe & Horne, 1985). The present results emphasize the importance of analyzing fully the effects of environmental contingencies (including discriminative stimuli) on the behavior of non-

humans in choice situations. They suggest that detailed analyses of all the relationships in the three-term contingency favored by behavior analysts (discriminative stimulus, operant behavior, reinforcer) may help to resolve some apparent discrepancies between human and nonhuman behavior in experimental conditions.

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