FREE-OPERANT FORGETTING: DELAYED STIMULUS CONTROL OF MULTIPLE-SCHEDULE PERFORMANCE

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Pigeons' responses were reinforced in two components of several multiple variable-interval variable-interval schedules of food reinforcement. In one component, the key was illuminated green for 15 seconds and white for 45 seconds. In the other component, the key was illuminated red for 15 seconds and white for 45 seconds. Values for the exponent of the power functions relating response ratios to reinforcement ratios were higher in the presence of the discriminative stimuli (green or red) than in the presence of white. Sensitivity of response ratios to changes in reinforcement ratios provided an index of the extent to which responding was under delayed stimulus control by prior discriminative stimuli.

Key words: forgetting, delayed stimulus control, multiple variable-interval schedules, key peck, pigeon

Procedures for studying remembering or forgetting examine the control over discriminative behavior by stimuli that occur some time before the response. In the delayed matching-to-sample procedure, for example, the sample stimulus that occasions a subsequent choice response is temporally separated from the response by a delay interval. Stimulus control is thus delayed (Branch, 1977; McKenzie & White, Note 1). The decrease in choice-response accuracy reflecting weakened control by prior stimuli defines "forgetting."

Delay-interval functions from discrete-trial procedures such as delayed matching to sample are generated by sampling discriminative behavior after different delay intervals following the prior stimulus, thus capturing the notion that the "trace" of the sample stimulus decays during the delay interval (Roberts & Grant, 1976). In order to demonstrate the diminished stimulus control characteristic of forgetting, it is not necessary, however, to incorporate an explicit delay interval such as blackout in the forgetting procedure. Instead, forgetting can be measured simply by the systematic diminution of the response differential (indicative of weakened stimulus control) as time progresses

since presentation of the discriminative stimuli.

In the present paper we describe a free-operant procedure for examining forgetting based on a standard multiple schedule or successive discrimination where two components and associated reinforcement schedules alternate successively. In our procedure the first 15 sec of each component were signaled by different discriminative stimuli (green or red), and the remainder of both components was signaled by identical stimuli (white). Responding in the white stimulus was under delayed stimulus control by the prior green or red. The response differential was, however, determined both by the prior stimuli (green or red) and by the prevailing reinforcement differential. By varying reinforcement frequency we were able to determine the sensitivity with which response ratios varied with changes in reinforcement ratios according to the power function given by Equation 1 (Davison & Ferguson, 1978; Lander & Irwin, 1968; McLean & White, 1981):

$$\frac{P_1}{P_2} = c \left(\frac{R_1}{R_2} \right)^a \quad (1)$$

In Equation 1, P and R denote response and reinforcement frequencies respectively, and their subscripts identify the components in which they occur. The exponent a describes the sensitivity of response ratios to changes in reinforcement ratios. The constant c describes inherent bias towards one or other component. In the present experiment, the sensitivity to

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reinforcement of ratios of responses occurring in the presence of the discriminative stimuli (green or red) was compared to the sensitivity of ratios of responses occurring in the presence of the white stimulus that followed red or green. Delayed stimulus control was thus measured by sensitivity (*a*) of responding occurring in the absence of the prior red or green discriminative stimuli.

METHOD

Subjects

Four adult homing pigeons with a year's previous experimental experience in concurrent schedules were maintained at 80% of their free-feeding weights. Grit and water were available in the living cages, and supplementary feeding ensured maintenance of the prescribed weights. Daily sessions were conducted for each bird unless its weight was outside $\pm 5\%$ of the prescribed weight.

Apparatus

A sound-attenuating experimental chamber with internal dimensions of 32 by 34 by 36 cm contained an intelligence panel with a central 2.5-cm diameter translucent response key, 25 cm from the grid floor, and also a second key that remained unlit and inoperative. A central hopper opening allowed 2.5-sec access to wheat. There was no houselight. The response key was illuminated green, red, or white, except during reinforcement when the hopper was illuminated. A force of .15 N was sufficient to operate the center key. Each response was followed by .04-sec offset of the keylight. Experimental events were controlled by solid-state apparatus in an adjacent room.

Procedure

The prior experimental experience rendered preliminary training unnecessary, and all birds were introduced to the first condition in the first session. Each session comprised 48 60-sec components. In Component 1, the key was illuminated green for 15 sec and then white for 45 sec. In Component 2, the key was illuminated red for 15 sec then white for 45 sec. Components 1 and 2 alternated in direct succession. Responses were recorded during the first, second, and fourth 15-sec subintervals of each component. (Responses in the third subintervals were not recorded owing to equipment

shortage.) Reinforcers were recorded during the total 60 sec of each component.

During each of six different conditions, responding during Component 1 (green and white) was reinforced according to one variable-interval (VI) schedule of reinforcement, and responding during Component 2 (red and white) was reinforced according to a second, independent VI schedule. Reinforcers set up but not obtained at the end of a component were not canceled. The average interreinforcement intervals of the constant-probability VI schedules were chosen to keep total reinforcement frequency over both components constant. Each condition was conducted for a minimum of 25 daily sessions and until performance was stable. The stability criterion was that in each of five consecutive sessions, responses in the first 15 sec of the richer component, as a proportion of total responses in the first 15 sec of both components, did not exceed $\pm 5\%$ of the mean response proportion for the five sessions. Table 1 gives the values of the VI schedules in each component of the six multiple-schedule conditions (in the order in which they were conducted) and also the number of sessions required for the performance of each bird to become stable.

RESULTS AND DISCUSSION

Table 1 gives the total response frequencies in the first, second, and fourth 15-sec subintervals of each component, and total reinforcement frequencies obtained in each component summed over the last five sessions of each multiple-schedule condition for each bird. Subsequent analyses were based on these five-session totals that represent stable performance. Table 1 shows that response differentials in each subinterval became smaller as the component progressed. Changes in both components generally contributed to the decrease in response differentials, although it seemed that larger changes appeared in the leaner component of some conditions, namely an increase in responding as the component progressed.

For each subinterval, response frequencies in Component 1 were divided by response frequencies in Component 2. Figure 1 plots logarithms of ratios of responses in each subinterval as a function of ratios of reinforcement frequencies in the two components. The logarithmic form of Equation 1 predicts a linear

Table 1

Response frequencies in first, second, and fourth 15-sec subintervals and reinforcer frequencies in each component summed over the last five sessions of each multiple schedule condition, and sessions conducted in each condition.

Condition		Sessions	Component 1 Responses			Component 2 Responses			Reinforcers		
			First	Second	Fourth	First	Second	Fourth	Component 1	Component 2	
Bird C1											
1.	VI 280	VI 56	53	342	1479	2813	2980	3324	3729	8	106
2.	VI 93	VI 93	26	3706	1601	2197	3069	2205	2288	64	66
3.	VI 56	VI 280	30	3387	2476	2815	2109	1974	2412	113	20
4.	VI 140	VI 70	26	2692	2269	2400	2983	2333	2332	53	87
5.	VI 70	VI 140	25	3673	2426	2682	2740	2427	2654	91	47
6.	VI 56	VI 280	28	3301	2352	2522	798	1899	2415	115	22
Bird C2											
1.	VI 280	VI 56	52	1896	1770	2123	2179	2328	2185	10	114
2.	VI 93	VI 93	31	2716	2592	2833	2302	2695	2798	68	68
3.	VI 56	VI 280	34	2875	3453	3317	1758	2107	2988	111	19
4.	VI 140	VI 70	29	2576	2668	2766	2726	2782	2707	54	87
5.	VI 70	VI 140	28	2876	2862	2844	2563	2681	2960	88	50
6.	VI 56	VI 280	28	2749	2728	2761	1828	2142	2807	115	27
Bird C3											
1.	VI 280	VI 56	54	585	2172	3540	3285	3286	3228	13	112
2.	VI 93	VI 93	25	3505	3011	3980	3541	3845	4001	68	67
3.	VI 56	VI 280	34	3724	3439	3463	1963	2240	3664	111	24
4.	VI 140	VI 70	25	2603	3335	3440	3318	3306	3447	53	88
5.	VI 70	VI 140	25	3810	3904	3772	2671	3166	3780	84	42
6.	VI 56	VI 280	28	3637	3679	3738	2157	2638	3882	115	26
Bird C4											
1.	VI 280	VI 56	51	279	1045	1942	2287	2001	1660	17	101
2.	VI 93	VI 93	27	1328	821	880	1121	1138	1026	66	66
3.	VI 56	VI 280	33	1225	847	638	597	399	776	113	24
4.	VI 140	VI 70	28	1130	1414	1510	1706	1613	1596	50	82
5.	VI 70	VI 140	25	2076	1833	1594	1150	1232	1650	95	35
6.	VI 56	VI 280	26	1307	1569	1391	854	1090	1393	115	26

relation between log response ratios and log reinforcement ratios, where the slope of the function gives a measure of sensitivity (a) and the intercept indexes bias ($\log c$). Linear functions were fitted to the data in Figure 1 by the method of least squares. The generally low values of the standard error for each function (Figure 1) indicate that the logarithmic form of Equation 1 gave a satisfactory account of the data for each subinterval. Values of bias ($\log c$) given in Figure 1 were generally small and did not change systematically for different subintervals.

Sensitivity measures, given by the values for the exponent a in Figure 1, were high in the presence of the red and green discriminative stimuli for Birds C1, C3, and C4, intermediate in the second 15-sec subinterval in the absence

of the discriminative stimuli, and were near zero for the fourth subinterval. For Bird C2, values of a were overall low but generally decreased over subintervals consistent with the marked reduction for Birds C1, C3, and C4. In summary, the systematic reduction in sensitivity of response ratios to reinforcement ratios with increasing time since presentation of prior discriminative stimuli, relative to high values for sensitivity in their presence, demonstrates the diminution of stimulus control when free-operant responding occurs following a delay since presentation of the discriminative stimuli.

Response differentials in the presence of white may have been determined by other sources of control such as a temporal discrimination resulting from the direct alternation of

Fig. 1. Logarithms of response ratios in first, second, and fourth subintervals of the multiple-schedule components, as a function of logarithms of reinforcement ratios. Values for slope (a), intercept ($\log c$), and standard error (se) are given for each least-squares regression line. The origin for each function is indicated by a cross.

components, or discrimination of reinforcer frequencies. The extent of the influence of such sources of control is an empirical question to be dealt with in further research. However, they may be minimally effective, as indicated by the absence of response differentials in the fourth subinterval (near-zero sensitivity). Our conclusion that responding in white, particularly during the second subinterval, was under delayed control by the prior stimuli, is consistent with Ferster and Skinner's (1957) conclusion that the discriminative stimulus (or "prime") inserted at the beginning of the fixed interval of a mixed FR FI schedule "may control the bird for the balance of the interval" (p. 630).

Wilkie and Wilson (1977) and Honig and Wasserman (1981) described delayed stimulus-control procedures in which responses were reinforced during brief intervals following offset of one stimulus and were not reinforced following another. Both procedures were similar to ours in that discrimination ratios derived from response frequencies in the absence of discriminative stimuli gave an index of delayed

control. In effect, our experiment extended these studies to free-operant performance in multiple variable-interval schedules. Honig and Wasserman (1981) compared their "delayed discrimination" procedure to a variant of the successive matching-to-sample procedure in which reinforcement for responding in one of two test stimuli was conditional upon the value of the prior sample stimulus (Nelson & Wasserman, 1978). Their study indicates that delayed conjoint stimulus control by sample and test stimuli in the conditional discrimination may be weaker than delayed control by the sample stimuli alone. Delayed-discrimination procedures such as ours may therefore provide a more direct means of assessing control by prior discriminative stimuli, compared to standard matching-to-sample procedures in which the conditional discrimination incorporates an additional source of stimulus control.

An important difference between the present experiment and Wilkie and Wilson's (1977) study is that the latter demonstrated delayed stimulus control in a generalization test where responding following prior stimuli varied sys-

tematically with the dimensional value of the prior stimulus. In the present experiment, stimulus control was assessed in terms of the extent to which response ratios were sensitive to changes in reinforcement ratios. The present experiment converged with Wilkie and Wilson's in its approach to delayed stimulus control. However, measurement of sensitivity changes as a means of quantifying delayed stimulus control has the distinct advantage of taking into account the reinforcement differential that is responsible for generating differential responding.

REFERENCE NOTE

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