INHIBITORY STIMULUS CONTROL AND THE MAGNITUDE OF DELAYED REINFORCEMENT¹

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The key pecking of pigeons was reinforced according to a variable-interval 1-min schedule during each of two successively presented stimuli. When the key was illuminated by a black line on a white background, reinforcement was delayed for 10 sec. When the key was illuminated by a plain white light, reinforcement was not delayed. For half of the subjects, the delayed reinforcer was 4.0-sec access to mixed grain, and for the remaining subjects it was 1.5-sec access. The immediate reinforcer was 1.5-sec access for all subjects. All subjects responded at a lower rate during the presentation of the black line; no between-group difference in terms of terminal response rate during the presentation of the line was found. However, subjects that received 4.0 sec of delayed reinforcement responded at a lower terminal rate during presentation of the plain white light than subjects that received 1.5 sec of delayed reinforcement. A subsequent generalization test along the line-orientation dimension produced flatter U-shaped gradients for subjects that received 4.0-sec of delayed reinforcement.

The multiple variable-interval extinction schedule has been one of the most frequently employed training procedures before testing for stimulus generalization (see, for example, Terrace, 1966a; 1972a). Under this schedule, the organism is exposed to successive periods of variable-interval (VI) reinforcement and extinction, with each of these periods associated with a different exteroceptive stimulus. If these stimuli lie on orthogonal dimensions, it is possible to assess independently generalization gradients around each stimulus. With orthogonal stimulus dimensions, all stimuli on one dimension are equally distant from all stimuli on the other dimension, thus allowing the experimenter to vary the distance of subsequent generalization test stimuli from one training stimulus without moving "closer to" or "farther from" the other training stimulus. A generalization test along the dimension that contains the stimulus associated with the variable-interval schedule yields an inverted U-shaped gradient, the peak of which is located at the training stimulus (e.g., Jenkins and Harrison, 1960), while a test along the dimension containing the stimulus associated with extinction produces a U-shaped gradient,

the nadir of which is located at the training stimulus (e.g., Honig, Boneau, Burstein, and Pennypacker, 1963; Jenkins and Harrison, 1962). These gradients have been taken by several investigators (e.g., Jenkins, 1965; Terrace, 1966a; 1966b; 1967; 1972a; 1972b) to define excitatory and inhibitory stimulus control, respectively.

Interestingly, the U-shaped gradient is not limited to the special multiple schedule that has an extinction component, as it has been demonstrated around the stimulus associated with the second component of a multiple variable-interval 1-min variable-interval 5-min schedule (Weisman, 1969), multiple variable-interval differential-reinforcement-of-low-response-rates schedule (Weisman, 1969), multiple variable-interval differential-reinforcement-of-other-behavior schedule (Weisman, 1970), multiple variable-interval variable-time schedule (Weisman and Ramsden, 1973), and a multiple variable-interval 1-min variable-interval 1-min schedule in which reinforcement is delayed during the second component (Richards, 1973).

While several studies (e.g., Farthing and Hearst, 1968; Hearst, 1971; Lyons, 1969; Selekman, 1970; Terrace, 1966b; Yarczower, 1970) have examined variables that affect the steepness of the U-shaped gradient generated around a stimulus associated with an extinc-

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tion component, little concern has been evidenced regarding variables affecting the steepness of the U-shaped gradient around stimuli associated with positive schedules of reinforcement. The present study examined one such variable—magnitude of reinforcement. More specifically, subjects were exposed to a multiple VI 1-min VI 1-min schedule in which the reinforcer was delayed during one component; for half of the subjects, the magnitudes of immediate and delayed reinforcement were equal; for the remaining subjects, the magnitude of delayed reinforcement was greater. Of major concern was the nature and slopes of subsequently obtained generalization gradients around the stimulus associated with the delayed reinforcement component.

METHOD

Subjects

Thirty four experimentally naive, adult, female White Carneaux pigeons, obtained from the Palmetto Pigeon Plant, were maintained at approximately 80% of their free-feeding weights.

Apparatus

A Kodak Ektagraphic slide projector, Model B, equipped with a 7.5-cm lens and mounted 25.4 cm behind the center key of a standard operant conditioning chamber (Lehigh Valley Electronics) was used to project the training stimuli (S1: a homogeneous white light; S2: a 0.78-mm thick black line, with a horizontal orientation in Experiment IA and a vertical orientation in Experiments IB and II, on a white surround) and the generalization test stimuli (S1, S2, and the black line, with departures of $+30^\circ$, $+60^\circ$, -30° , -60° , and $\pm 90^\circ$ from S2, on a white surround). Overall illumination of the chamber was provided by the standard houselight (CM 1820) and two pilot lights (GE 1819), which were mounted slightly above the covered side keys. A red pilot light (CM 1829), mounted on the chamber's back wall, was illuminated during the 10-sec timeouts of S1 and 10-sec delay periods of S2.

Standard scheduling and recording equipment was housed in an adjacent room. The chamber's ventilation fan and the projector's cooling fan provided the only masking noise.

Procedure

Experiment IA. During the shaping of the key peck, only the keylight was illuminated, and the duration of reinforcement was manually controlled by the experimenter. In subsequent sessions, the houselights were illuminated, except as noted below, and the duration of reinforcement was controlled by a photocell located within the food magazine and a standard timer; the timer began when the subject placed its head into the magazine and interrupted the photobeam. After the key peck was well established, the schedule of reinforcement was gradually increased until a fixed-ratio 20 schedule was attained. The 10 subjects then received three sessions of training on a VI 1-min schedule. A 1-sec blackout (during which responding was nonfunctional) separated 30-sec illuminations of the key by S1 except during the early training sessions (which contained no blackouts). This 30-sec duration excluded reinforcement time. Throughout training, timing of the first stimulus presentation of each session was initiated by the subjects' first key peck. Except as noted above, the reinforcer was 1.5-sec access to mixed grain.

Subjects were then assigned to one of two groups so as to be matched in terms of response rate during the last session of simple VI training. More specifically, subjects were ranked in terms of their response rate, and each subject paired with another (lowest and second lowest, third lowest and fourth lowest, etc.); one of the paired subjects was then randomly assigned to one group and the remaining subject assigned to the second group. Both of the groups received 14 sessions of training on a multiple VI 1-min VI 1-min schedule that had reinforcement delayed for 10 sec during one component. S1 and S2 illuminated the key during the immediate and delayed reinforcement components, respectively. The two groups differed in terms of the magnitude of reinforcement associated with the delay component—1.5-sec *versus* 4.0-sec access to mixed grain. For both groups, 1.5-sec of mixed grain was delivered during the immediate reinforcement component. (Due to an apparatus failure, S-9 was exposed to a multiple VI 1-min extinction schedule for about 20 min during the fifth session under the multiple schedule.) During these

sessions, each of which contained 45 stimulus presentations, responding was nonfunctional during the 1-sec blackouts that separated successive 30-sec stimulus presentations. This 30-sec duration excluded delay, timeout, and reinforcement time. The order of stimulus presentation was mixed with the restriction that no stimulus could occur more than three times in succession. While reinforcement was never delayed during S1, 10-sec timeouts were scheduled according to an independent, but identical, VI 1-min schedule. The red pilot light provided the chamber's only illumination during the delay and timeout periods; responding during these periods had no scheduled consequences. If a reinforcement and timeout was set up concurrently during S1, the first response produced the reinforcer and the next response produced the timeout. Reinforcements and timeouts set up, but not received during one stimulus presentation, carried over to the next presentation of that stimulus. This procedure of scheduling the illumination of the pilot light with equal frequency during S1 and S2 controls for any possible effects of the pilot light, *per se*. Thus, if all scheduled timeouts and reinforcements are obtained, the only difference between the components would be S1's association with 1.5-sec immediate reinforcement and S2's association with 1.5- or 4.0-sec (depending on the group) delayed reinforcement.

The session following completion of training on the multiple schedule began with a period of additional training (22 stimulus presentations) and ended with a test for generalization. The red pilot light was never illuminated during the generalization test, which was conducted during extinction. Each of the seven generalization test stimuli (the homogeneous white light and the six line orientations on a white background) were presented in random order within each of six blocks. Five different random sequences were used, with previously matched subjects receiving the same sequence. As in training, 30-sec stimulus presentations were separated by 1-sec blackouts.

Experiment IB. Several weeks after the completion of Experiment IA, 10 naive subjects were exposed to training and testing procedures identical to those described above, except that S2 was a black vertical line on a white surround.

Experiment II. Experiment II sought to determine whether the larger amount of food consumed by subjects in the 4.0-sec groups (before training sessions terminated) was responsible for the results obtained in Experiments IA and IB. The remaining 14 naive pigeons were thus exposed to training and testing procedures identical to those employed in Experiment IB, except for their being prefed about 30 min before the sessions of multiple schedule training and generalization testing. Subjects in the 1.5-sec and 4.0-sec groups were prefed 5.0 and 1.5 g of mixed grain, respectively. It was empirically determined that subjects in Experiment IB, which received 4.0-sec of reinforcement during S2, consumed about 3.5 g more grain per session than subjects that received 1.5-sec of reinforcement during S2.

RESULTS

The analysis of the present data proceeded in terms of the matched-subjects design that was employed; it should be recalled that the subjects within each experiment were matched in terms of pretraining response rate (and only then assigned to groups) and that these matched subjects received an identical sequence of stimuli during the generalization test. More specifically, in assessing the effects of reinforcement magnitude, the within-subject-pair differences were first examined. Then, any consistent differences were analyzed by matched t-tests (one-tailed tests were employed because it was anticipated that any differences would be in the direction of higher S1 response rates, lower S2 response rates, and steeper generalization gradients in the 1.5-sec groups) or the appropriate repeated measures analysis of variance.

Table 1 summarizes the individual subject's response rates during training, the absolute number of responses emitted to S1 and S2 during the generalization test, and the percentage of responses emitted to S2 during the generalization test. Within each row, a column's first numerical entry is for the subject that received 1.5 sec of delayed reinforcement, and the second, parenthesized, entry is for the matched subject that received 4.0 sec of delayed reinforcement. A "+" indicates that the first entry is larger, a "-" indicates the converse, and a "0" indicates no difference.

Table 1

		<i>Pretraining Response Rate</i>	<i>Mean Response Rate During Last Two Sessions of Multiple Schedule Training to:</i>		<i>Total Responses During Generalization Test to:</i>		<i>Percentage of Responses During the Generalization Test Emitted to:</i>
			<i>S1</i>	<i>S2</i>	<i>S1</i>	<i>S2</i>	<i>S2</i>
Exp. IA	Subjects						
	1(2)	−22.36 (31.98)	+ 70.21 (45.55)	−15.72 (21.34)	+208 (199)	− 42 (65)	− 6.48 (11.44)
	3(4)	−17.57 (21.99)	+ 36.79 (27.68)	+23.64 (16.45)	− 67 (74)	− 24 (58)	− 8.25 (16.34)
	5(6)	+37.33 (33.23)	+ 90.92 (65.42)	−19.75 (36.99)	+259 (210)	− 61 (77)	− 9.98 (10.29)
	7(8)	+44.31 (42.98)	+108.45 (89.93)	−30.41 (43.38)	+410 (393)	−153 (164)	−12.44 (13.56)
	9(10)	−49.16 (60.54)	+ 91.65 (89.47)	−33.37 (46.52)	+316 (225)	+130 (118)	+17.06 (12.73)
	Means	34.15 (38.14)	79.60 (63.61)	24.58 (32.94)	252.00 (220.20)	82.00 (94.40)	10.84 (12.87)
Exp. IB	11(12)	+29.86 (8.53)	+ 69.55 (58.01)	−25.61 (31.43)	+210 (182)	− 81 (82)	−11.22 (12.24)
	13(14)	+31.54 (31.22)	+ 60.48 (47.25)	−27.71 (38.41)	+201 (133)	− 70 (109)	−12.39 (15.68)
	15(16)	+48.00 (39.57)	− 41.96 (60.77)	−24.87 (37.05)	−122 (197)	− 41 (126)	−10.46 (16.24)
	17(18)	−60.68 (64.06)	+104.33 (66.35)	+52.73 (33.94)	+290 (163)	+131 (89)	−10.85 (14.38)
	19(20)	+38.28 (35.14)	+ 80.17 (45.32)	+33.73 (17.27)	+275 (152)	− 70 (77)	+14.43 (13.92)
	Means	41.67 (35.70)	82.19 (55.54)	32.93 (31.62)	219.60 (165.40)	78.60 (96.60)	11.87 (14.49)
Exp. II	21(22)	+21.16 (16.40)	− 58.98 (94.40)	−36.12 (62.06)	−211 (245)	− 83 (164)	−11.48 (16.16)
	23(24)	+23.04 (22.24)	+ 82.98 (34.39)	+34.83 (27.06)	+227 (77)	+ 78 (64)	−12.11 (16.16)
	25(26)	−27.11 (28.65)	+ 77.04 (59.00)	− 7.38 (32.47)	+182 (151)	− 18 (69)	− 5.41 (13.64)
	27(28)	−31.71 (34.35)	+ 58.34 (41.60)	+41.07 (25.03)	+222 (101)	+123 (62)	−12.07 (15.54)
	29(30)	−35.77 (37.42)	+ 70.67 (46.47)	+52.96 (35.61)	+166 (162)	+117 (114)	−13.90 (15.00)
	31(32)	−39.03 (42.22)	+101.14 (61.94)	−35.53 (46.04)	+245 (125)	− 68 (127)	−10.23 (19.30)
	33(34)	+52.55 (42.08)	+129.15 (97.11)	+87.27 (43.25)	+360 (308)	+227 (144)	+14.53 (13.73)
	Means	32.91 (31.91)	82.61 (62.13)	42.17 (38.79)	230.43 (167.00)	102.00 (106.29)	11.39 (15.65)

Examination of the first column shows no consistent difference between groups during the last session under the simple V1 1-min schedule. However, by the end of training on the multiple schedule, subjects receiving 1.5 sec of delayed reinforcement were consistently responding at a higher rate during S1 than subjects receiving 4.0 sec of delayed reinforcement. Statistical analyses (Experiment IA: $t = 3.53$, $df = 4$, $p < 0.05$; Experiment IB: $t = 1.55$, $df = 4$, $p \approx 0.10$; Experiment II: $t = 1.99$, $df = 6$, $p < 0.05$) tend to support these individual comparisons. No consistent difference was found in the terminal response rate during S2, with an acceptable level of significance being approached in only Experiment IA ($t = 1.94$, $df = 4$, $p \approx 0.06$). There was little between-group difference in terms of S1 reinforcement, S1 timeout, or S2 reinforcement rates during training; these rates were also approximately equal within the individual birds.

During the generalization test, 14 of the 17 comparisons between previously matched subjects showed more responses to S1 by the subject receiving 1.5 sec of delayed reinforce-

ment. The results of matched t-tests on the number of generalization test responses to S1 approached standard levels of significance (Experiment IA: $t = 1.83$, $df = 4$, $p \approx 0.07$; Experiment IB: $t = 1.46$, $df = 4$, $p \approx 0.11$; Experiment II: $t = 1.43$, $df = 6$, $p \approx 0.10$). Comparison of matched subjects in terms of the number of S2 responses showed no consistent pattern across the experiments, and although the mean was higher for the 4.0-sec group in all experiments, an acceptable level of significance was approached in only Experiment IA ($t = 1.88$, $df = 4$, $p \approx 0.07$).

Relative generalization gradients for individual subjects are presented in Figures 1 and 2; the dependent variable in these figures is the number of responses to the test stimulus divided by the number of responses to S2 during the generalization test. Closed and open circles represent subjects in the 1.5-sec and 4.0-sec groups, respectively. With the exception of Subjects 9, 19, 24, 32, and 33, the individual gradients are U-shaped, with their nadirs located at or near S2. A comparison of the gradients of the 17 previously matched subject pairs, shows 13 cases in which

Fig. 1. Relative generalization gradients for each bird in Experiments IA and IB. The dependent variable is the number of responses to the test stimulus divided by the number of responses to S2 during the generalization test. For the sake of symmetry, the amount of relative responding to the vertical line has been plotted at both $+90^\circ$ and -90° for subjects shown in Experiment IA. Similarly, the amount of relative responding to the horizontal line has been plotted at both $+90^\circ$ and -90° for subjects in Experiment IB. Subjects that received 1.5 sec and 4.0 sec of delayed reinforcement are indicated by closed and open circles, respectively. A "+" indicates that of the matched subjects, the one receiving 1.5 sec of delayed reinforcement has a steeper gradient. A "-" indicates that the subject receiving 4.0 sec of delayed reinforcement has a steeper gradient. A "0" indicates no clear difference.

the subject that received 1.5 sec of delayed reinforcement had the steeper gradient (a "+" under the legend in each panel of Figures 1 and 2 identifies these cases). In only three of the comparisons is the gradient steeper for the subject that received 4.0-sec of delayed reinforcement (these are indicated by a "-"), and the validity of the comparison between S-9 and S-10 is questionable, since, as previously stated, there was a temporary apparatus failure during the training of S-9. While the gradients of S-33 and S-34 are similar at many points, it should be noted that only S-34's gradient is consistently U-shaped. In the remaining matched pair (S-5 and S-6), a definite conclusion is not possible regarding differential steepness of the gradients (indicated by a "0").

Figure 3 shows the mean relative generalization gradients for each group in the three separate experiments. The gradients for the 1.5-sec groups are all U-shaped and each has their nadir at S2. Two of the three U-shaped gradients for the 4.0-sec groups, however, have their nadirs displaced 30° from S2. In each experiment, the 1.5-sec group gradient is above the 4.0-sec group gradient at all points, except S2 which is equated by the particular relative generalization measure employed. The irregularity on the right side of the 1.5-sec group gradient in Experiment II is due to the large amount of relative responding to the $+60^\circ$ line by S-25. The statistical analysis of these gradients was conducted in terms of the matched-subjects design that was employed. Thus, the gradients in Experiments IA and IB were subjected to a $2(\text{groups}) \times 6(\text{stimuli}) \times 5(\text{blocks of subjects})$ analysis of variance with repeated measures on the second factor; the gradients in Experiment II were subjected to a similar $2(\text{groups}) \times 6(\text{stimuli}) \times 7(\text{blocks of subjects})$ analysis of variance. In each of the experiments, significant main effects for stimuli were found (Experiment IA: $F = 11.97$, $df = 5/20$, $p < 0.001$; Experiment IB: $F = 7.68$, $df = 5/20$, $p < 0.005$; Experiment II: $F = 3.53$, $df = 5/30$, $p < 0.05$). Differences between the group gradients also approached standard levels of significance in each experiment (Experiment I: groups-by-stimuli interaction, $F = 2.28$, $df = 5/20$, $p \approx 0.09$; Experiment IB: main effect for groups, $F = 5.93$, $df = 1/4$, $p \approx 0.07$; Experiment II: main effects for groups, $F = 4.73$, $df = 1/6$,

Fig. 2. Relative generalization gradients for each bird in Experiment II. The dependent variable is the number of responses to the test stimulus divided by the number of responses to S2 during the generalization test. For the sake of symmetry, the amount of relative responding to the horizontal line has been plotted at both $+90^\circ$ and -90° . Subjects that received 1.5-sec and 4.0-sec delayed reinforcement are indicated by the closed and open circles, respectively. A "+" indicates that of the matched subjects, the one receiving 1.5-sec delayed reinforcement has a steeper gradient. A "-" indicates that the subject receiving 4.0-sec delayed reinforcement has a steeper gradient. A "0" indicates no clear difference.

Fig. 3. Mean relative generalization gradients for each group in Experiments IA, IB, and II.

$p \approx 0.07$, and groups-by-stimuli interaction, $F = 2.09$, $df = 5/30$, $p \approx 0.09$).

The last portion of Table 1 shows the percentage of responses that were emitted to S2 during the generalization test. As these percentages are based on the total responses emitted to the six line orientations, chance responding (*i.e.*, no stimulus control) would show 16.67% to S2. Roughly, the lower the percentage is below 16.67%, the greater the degree of stimulus control. While only S-9

(1.5-sec group of Experiment IA) and S-32 (4.0-sec group of Experiment II) responded at above-chance levels to S2, four of the subjects that received 4.0 sec of delayed reinforcement (S-4, S-16, S-22, and S-24) emitted more than 16% of their responses to S2. A comparison of the 17 subject pairs shows 14 instances in which the lower percentage was obtained by the subject that received 1.5 sec of delayed reinforcement. In each experiment, the mean percentage was also lower for the 1.5-sec group than for the 4.0-sec group. Statistical analysis showed a significant difference in Experiment IB ($t = 2.43$, $df = 4$, $p < 0.05$) and in Experiment II ($t = 3.18$, $df = 6$, $p < 0.01$), but not in Experiment IA ($t = 0.96$, $df = 4$, $p < 0.20$).²

DISCUSSION

The present study showed that the U-shaped gradient generated around a stimulus associated with a delayed reinforcement component in a multiple schedule may be flattened by increasing the magnitude of the delayed reinforcer. Without necessarily implying "preference" as the determinant of the U-shaped gradient, the compatibility between the present results and the reported weakening of and reversal in the preference for immediate reinforcement with increasing magnitudes of delayed reinforcement (*e.g.*, Davenport, 1962) should be noted. In fact, subsequent research with larger differences between the magnitudes of immediate and delayed reinforcement would be instructive and might yield an inverted U-shaped gradient around the stimulus associated with the delayed reinforcement component and a U-shaped gradient around the stimulus associated with the immediate reinforcement component.

While the present study clearly showed weaker control by the stimulus associated with the delayed reinforcement component that had the larger magnitude of reinforcement, the permanence of this effect was not determined. Rather than permanently weakening

²If the S-9 and S-10 percentages are omitted from the analysis because of the apparatus failure that occurred during S-9's early training, an acceptable level of significance is also approached in Experiment IA ($t = 2.01$, $df = 3$, $p \approx 0.07$).

the control exerted by S2, it is possible that the large magnitude of delayed reinforcement only impeded the development of strong stimulus control and that with more extended training little difference between the groups might have been observed. The effects of extended training under the procedures of both the 1.5-sec and 4.0-sec groups would be most informative. Moreover, much extended training might yield qualitative changes (such as an inversion) in the gradients of both groups.

While the suggestion has been made (*e.g.*, Jenkins, 1965; Terrace, 1966*a*; 1966*b*; 1967; 1972*a*; 1972*b*) and debated (Farthing and Hearst, 1968; Hearst *et al.*, 1970; Hearst, 1972) that the U-shaped gradient is indicative of inhibition, the magnitude of any inhibitory effects may be unmeasurable by the slope of the gradient. Rather, the possibility exists that while a somewhat flat U-shaped gradient may indicate the presence of inhibition and weak stimulus control, the stimulus might also exert a strong inhibitory influence (that generalizes a great deal along the dimension). Thus, from the gradients in the present study it may not be possible to conclude that S2 exerted less inhibition over responding when it was associated with a large magnitude of reinforcement. In fact, in terms of absolute rate of response to S2, there was no consistent difference between the groups. In order to assess differences in the magnitude of inhibition, it would seem necessary to proceed along the lines suggested by Hearst and his colleagues, *e.g.*, to employ the resistance-to-(immediate) reinforcement and combined-cue techniques.

Although the design of the present study prevented a direct assessment of behavioral contrast, previous studies (Keller, 1970; Richards, 1972; Wilkie, 1971) have shown delayed reinforcement during one component of a multiple schedule to be effective in producing this type of interaction, at least with equal magnitudes of reinforcement during the component schedules. In the present study, the lower S1 response rates during training and generalization testing by the 4.0-sec groups, as compared to the 1.5-sec groups, would thus seem to indicate either less behavioral contrast or an absence of behavioral contrast in subjects that received the larger magnitude of delayed reinforcement. These

differences were found without any consistent between-group differences in S2 response rate.

While subjects in the 4.0-sec groups received more total food reinforcement within a session than subjects in the 1.5-sec groups, motivational differences between the groups were not responsible for the differences in terminal S1 response rates or subsequently obtained generalization gradients. After determining that subjects in the 4.0-sec groups consumed about 3.5 g more grain during each session, subjects in the 1.5-sec group of Experiment II were prefed 3.5 g more grain than subjects in the 4.0-sec group. Experiment II also showed lower S1 terminal response rates and flatter generalization gradients around S2 for subjects in the 4.0-sec group.

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