EFFECTS OF STIMULUS CONTROL AND DEPRIVATION UPON DISCRIMINATIVE RESPONDING¹

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Discriminative responding in pigeons was studied under multiple variable-interval extinction schedules in which extinction was correlated with either a tone or a white keylight. The two procedures resulted in weak and strong stimulus control, respectively. In the first experiment, there was no interaction between schedule components when stimulus control was strong and reinforcement was omitted under the previously reinforced component. However, there was marked induction between components when stimulus control was weak and responding was extinguished under the previously reinforced component. In the second experiment, hours of food deprivation was varied under two levels of stimulus control. Deprivation mainly influenced response rates under the extinction stimulus, with greater absolute rate increases occurring the lower the existing level of stimulus control. Increases in responding during the extinction stimulus were four times as great from 24 to 72 hours of deprivation as from 24 to 48 hours under conditions of both high and low stimulus control.

Two general procedures have been employed in the study of operant discriminations: (1) Simultaneous discrimination—the subject responds to one of two or more stimuli that are presented concurrently; (2) Successive discrimination—the subject responds differentially to two or more stimuli presented sequentially. The latter procedure constitutes a multiple schedule when the stimuli are correlated with different schedules of reinforcement. In a discrimination, extinction is frequently one of the multiple schedule components.

Changes in responding during one component of a multiple schedule (the constant component) have frequently accompanied changes in behavior during the second component (the variable component), and are referred to as interactions. Contrast is the term used to describe changes in responding that are opposite in direction during the two multiple schedule components, while induction refers to changes in the same direction during the two components (Reynolds, 1961).

The present research involved two experiments that studied the influence of specific variables upon responding under a successive discrimination procedure. The rationale for the

first experiment was based partially upon the results of an earlier study in this laboratory (Powell, 1971a). Here, it was observed that when responding under the variable-interval (VI) and variable-ratio (VR) components of multiple VI-extinction and VR-extinction schedules was suppressed by punishment shock, there was a significant increase in responding under extinction at intermediate shock intensities. This constitutes positive behavioral contrast.

The initial goal of the first experiment was a systematic replication of the prior study, except that extinction was used instead of punishment to reduce responding during the previously reinforced multiple schedule component. In other words, reinforcement was no longer presented for responses in the presence of the stimulus that had been correlated with a VI schedule, while the extinction component was unchanged.

It has been suggested that the degree of stimulus control may be an important determinant of the type of interaction that takes place under multiple schedules (Wertheim, 1965; Pear and Wilkie, 1971). The latter authors have speculated that strong stimulus control results in contrast, while weak stimulus control leads to induction. A direct test of this hypothesis was carried out in the first experiment.

Recent evidence suggests that in a discrimination the degree of stimulus control that

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exists will interact with certain independent variables, such as deprivation, in the determination of discriminative responding (Powell, 1971b). This conclusion was based upon data drawn from a series of experiments that employed several deprivation procedures and discrimination tasks. The purpose of the second experiment was to test further the hypothesis of stimulus control-deprivation interaction, through independent variations of deprivation and stimulus control within the same subject. It was anticipated that this procedure would permit a more explicit and quantitative description of the relationship between the variables under study.

Different levels of stimulus control were attained in each experiment through the use of visual or auditory stimuli that were correlated with extinction. The visual and auditory stimuli resulted in strong and weak stimulus control, respectively.

EXPERIMENT 1: THE EFFECT OF EXTINCTION DURING THE VI COMPONENT OF A MULT VI-EXTINCTION SCHEDULE, WITH TWO LEVELS OF STIMULUS CONTROL.

METHOD

Subjects

Two adult male White Carneaux pigeons, each with an extensive experimental history, were maintained at approximately 90% of their free-feeding weights. Water and grit were available to the birds at all times in their home cages.

Apparatus

A Lehigh Valley pigeon test chamber, model 1519C was used. Mixed grain was the reinforcer with a grain hopper time of 3.0 sec for each bird. The keylight was turned off during the presentation of reinforcement. A Precision sine-square wave generator, model E-310 provided a tone that was correlated with extinction during Phase 2 of the experiment.

Procedure

Discrimination training. During preliminary training, the birds were exposed during alternate weeks, to the two discrimination pro-

cedures that were later to be studied in sequence (Phase 1 and Phase 2). This training continued for 10 weeks, with five weeks under each procedure. The aim was to verify that the two discrimination procedures would exercise substantially different levels of stimulus control for each bird, and this was achieved.

Mult VI-extinction with visual stimuli (Phase 1). This discrimination procedure, which had been in effect during alternate weeks of the preliminary training, consisted of a VI 60-sec schedule correlated with a red keylight (S^D) and extinction correlated with a white keylight (S^A). Experimental sessions were 80 min in duration with 8-min components of S^D and S^A alternating, except that the first component was always VI and was 16 min long. Thus, there were 48 min of S^D and 32 min of S^A in each session. Baseline training continued until each bird met a criterion of fewer than 100 responses during extinction in each of 10 consecutive sessions. This required 10 and 20 sessions for Birds 42 and 50, respectively.

The birds were studied next with extinction in effect throughout the session, while the discriminative stimuli continued to be presented in the same sequence. This procedure continued for each bird until it made fewer than 100 responses during the stimulus previously correlated with the VI schedule. After this criterion was achieved, the VI-60 sec schedule was reintroduced in the next session during S^D , while other procedures were unchanged. Reconditioning continued for five sessions, followed by a second cycle of extinction sessions until the criterion under this procedure was again achieved. This phase of the experiment terminated when four cycles each of extinction and reconditioning were completed.

Mult VI-extinction with an auditory stimulus correlated with extinction (Phase 2). This procedure was identical to Phase 1 except that the keylight was red at all times, and a square wave tone of 90 dB and 1234 Hz was present during each extinction component. The keylight was off during reinforcement, as in Phase 1. This procedure resulted in response rates during extinction that were much higher and more variable than in Phase 1, and it was not possible to achieve a stringent stability criterion. Accordingly, training was terminated when no trend could be discerned in extinction responding over 10 consecutive sessions.

Fig. 1. Response rates during successive cycles of the experiment with the white keylight as S^A . Reinforcement was present in S^D (VI schedule) under the odd-numbered cycles and absent in S^D under the even-numbered cycles. The mean and range of response rates over five sessions under S^D and S^A are presented for the odd-numbered cycles. Response rates under S^D and S^A are presented for each session during the even-numbered cycles, when reinforcement was withheld under S^D .

This required 36 and 23 sessions for Birds 42 and 50, respectively. The subjects were then studied for four cycles each of extinction and reconditioning, as in Phase 1.

RESULTS AND DISCUSSION

The multiple schedule in which the keylight colors were correlated with reinforcement and extinction (Phase 1) exercised a high degree of stimulus control over responding for both birds, as shown in Figure 1. There was very little responding under S^A , whether or not responding was reinforced under S^D . Kruskal-Wallis analyses showed that there was no difference in extinction responding under the two conditions (Bird 42: $H = 0.745$, $df = 1$, $p < 0.50$; Bird 50: $H = 0.546$, $df = 1$, $p < 0.50$). This analysis indicates that there was no interaction between components as responding under the VI schedule was extinguished, and also when VI responding recovered with the reintroduction of reinforcement.

Discriminative responding was much less accurate during Phase 2, where a tone (S^A) was correlated with the extinction component of the multiple schedule. The performance of

each bird could thus be characterized as exhibiting weak stimulus control. Figure 2 shows that responding under S^A decreased markedly when reinforcement was no longer presented during S^D . This constitutes negative induction, which is defined as a decrease in response rate in one component as a function of a decrease in a second component (Reynolds, 1961). Kruskal-Wallis analyses verified that there was significantly less responding under S^A when reinforcement was withheld during S^D in comparison to sessions where reinforcement was presented during S^D (Bird 42: $H = 27.438$, $df = 1$, $p < 0.001$; Bird 50: $H = 37.270$, $df = 1$, $p < 0.001$).

A comparison of response rates under the two components with reinforcement present or absent during S^D , shows a disproportionate decrease in responding under S^A with reinforcement absent. For Bird 42, 15% of its responses occurred under S^A with reinforcement present during S^D , while only 3% of the total responses occurred under S^A when reinforcement was absent during S^D . For Bird 50, responses during S^A decreased from 24% to 12% of the total when reinforcement was withheld during S^D . These statistics were calculated ac-

Fig. 2. Response rates during successive cycles of the experiment with tone as S^A . The data are presented in the same way as described under Figure 1.

according to the formula: response rate during extinction component divided by response rate during extinction component + response rate during VI component.

This type of analysis suggests that positive induction occurred when reinforcement was reintroduced during the VI component. That is, responding during S^A was enhanced by the presentation of reinforcement and concurrent increase in responding during the VI component.

The present results do not replicate the positive contrast effects found earlier during the extinction component of a multiple schedule, when responding was suppressed by punishment during the positively reinforced component (Powell, 1971a). Visual discriminative stimuli were used and a high degree of stimulus control was also attained during baseline training in that study, making it analogous to Phase 1 of the present experiment. There appear to be several plausible explanations for this difference. First of all, it has been shown that both punishment and extinction produce a decrease in responding, but the distribution of interresponse times differs between procedures (Holz and Azrin, 1963). So if these procedures act to decrease a specific behavior in different ways they may also have different effects upon other behaviors occurring in the same situation.

When positive contrast effects occurred under S^A in the previous study, reinforcement was still being obtained under S^D . The complete suppression of responding by severe punishment during S^D and consequent elimination of reinforcement was correlated with little responding during S^A . Similarly, the withholding of all reinforcement during S^D in the present study resulted in very low response rates under S^A .

Behavioral contrast has typically been observed when reinforcement rate was varied during one multiple schedule component, relative to the rate prevailing in the other component (Reynolds, 1961; Reynolds and Catania, 1961). The present procedure did not involve any systematic variation in reinforcement frequency during S^D . Reinforcement was either present at a fairly constant rate, or it was absent. It should be noted that both behavioral contrast (Terrace, 1968; Brownstein and Newsom, 1970) and induction (Hemmes and Eckerman, 1972) have been observed during one component of a multiple schedule when there was no change in reinforcement frequency during the second component.

In summary, these results show that the level of stimulus control that exists will influence both the degree and direction of interaction that takes place between the components of a multiple schedule.

EXPERIMENT 2: THE EFFECT OF DEPRIVATION UPON DISCRIMINATIVE RESPONDING WITH TWO LEVELS OF STIMULUS CONTROL

METHOD

Subjects and Apparatus

Four adult male White Carneaux pigeons, each with an extensive experimental history, were used; apparatus was the same as in Experiment 1.

Procedure

Discrimination training. Experimental procedures were identical to Experiment 1, except that there were sessions in which both S^As were present, with tone on during the first and fourth 8-min extinction components, whereas the white keylight was on during the second and third extinction components.

Preliminary training involved two phases, with tone present during the extinction components in the first phase. This procedure continued until responding was stable during both S^D and S^A components over 10 consecutive sessions. Stability was assessed by the absence of any trend in response rates over these sessions. As in Experiment 1, it was not pos-

sible to achieve a more stringent stability criterion because of marked variability in responding during the tone. The second training phase involved the multiple S^A procedure described above, which continued until the same stability criterion was achieved. The rationale for such extended training derived from the long experimental histories of these birds, and the session-to-session variability in responding under the tone that was found here and in Experiment 1. The number of training sessions for each bird is shown in Table 1. Body weights, which are stated as a percentage of the animal's free-feeding weight, were as follows: Bird 16-90%, Bird 20-86%, Bird 21-88%, Bird 30-86%.

Discriminative performance with changes in deprivation. The study of performance involved three phases: Phase 1—Both the tone and the white keylight employed as S^As in the same session, as described earlier. Phase 2—The tone and the white keylight employed singly as the S^A in a session, alternating by week. Phase 3—The tone only employed as the S^A. Deprivation was varied by withholding food for 24, 48, or 72 hr before the experimental sessions. The sequence of deprivation periods was generally as follows: 72, 24, 48, 24 hr. Thus, they were studied four days per week. The birds were given supplemental feeding after each session

Table 1

The number of sessions under each procedure. The tone was present during S^A components of the multiple schedule in Phase 1 of Discrimination Training. The tone and the white keylight served as S^A's during Phase 2 of Training and also Phase 1 of Discrimination Testing. During Phase 2 of testing, either the tone or the white keylight served as S^A in a session, and their presentation alternated by week. Phase 3 of Testing employed the tone alone as S^A.

Subject	Discrimination Training			Discrimination Testing w Deprivation			
	Hr of Dep.	Phase 1	Phase 2	Phase 1	Phase 2		Phase 3
					(Tone)	(White K-L)	
P16	24	60	41	12	18	20	19
	48			6	8	10	9
	72			9	9	10	11
P20	24	59	25	16	23	22	18
	48			11	12	10	9
	72			12	11	9	10
P21	24	43	31	17	21	19	18
	48			10	11	11	9
	72			10	10	11	10
P30	24	55	34	17	21	20	19
	48			8	11	9	12
	72			10	10	10	11

as required, so that the amount they gained during the session plus the supplemental feeding equalled 25 g. Consequently, they received approximately 100 g of grain per week, which was sufficient to maintain each bird at approximately the same weight level throughout the experiment. The number of sessions under each procedure is shown in Table 1. The accuracy of discrimination was assessed through calculation of a discrimination ratio based upon the formula:

$$\frac{\text{Resp. Rate under } S^D}{(\text{Resp. Rate under } S^D + \text{Resp. Rate under } S^A)}$$

Perfect discrimination would result in a ratio of 1.00; failure to discriminate would yield a ratio of 0.50.

RESULTS AND DISCUSSION

The multiple schedule with different keylight colors attained a much higher level of

Fig. 3. Mean discrimination ratios for each bird as a function of hours of deprivation under the two S^A conditions. The open points connected by solid lines represent performance when the white keylight was S^A . The filled points connected by dashed lines represent performance when the tone was S^A . Data points are based upon the total number of sessions under that condition as shown in Table 1.

stimulus control (more accurate discrimination) during training and throughout the experiment, than the schedule with tone-correlated extinction, even though training had been much more extended under the latter procedure. The mean discrimination ratios over the final 10 training sessions under the white keylight and the tone, respectively, were as follows: P16-1.00, 0.76; P20-0.99, 0.96; P21-0.94, 0.80; P30-0.95, 0.70. Figure 3, which summarizes individual discrimination over all phases of the experiment, shows that discrimination ratios were consistently above 0.90 when the white keylight was S^A and below 0.90 when tone was S^A , except for Bird 21.

Accuracy of discrimination declined as deprivation increased, with Bird 30 at 48 hr the only exception. The data also suggest that the decrease in accuracy was greater, the lower the level of stimulus control (accuracy) achieved during training. When tone was S^A , discrimination ratios were substantially higher for Birds 16, 21, and 30 under the 24-hr period when hours of deprivation varied than during the final training sessions when 24-hr periods of deprivation also preceded each session. As shown later, discrimination under this procedure improved gradually over the course of the experiment. However, since the three deprivation periods were equally distributed over time in the experiment, the relationships observed could not be attributed simply to improvement in performance with practice.

Figure 4 presents a plot of VI *versus* extinction response rates under the two discrimination procedures for the three deprivation times. The VI response rate did not increase as deprivation increased, except for Bird 30, but responding did increase substantially under both S^A s for each bird. This analysis shows that the decrease in discriminative accuracy resulted from disproportionate increases in responding under S^A as deprivation increased. Except for Bird 21, the absolute increase in responding was much greater with tone as S^A as compared to the white keylight.

While deprivation generally resulted in a greater absolute increase in responding under the tone in comparison to the white keylight, as shown in Table 2, the relative (%) increase in responding under the keylight was greater than under the tone. This analysis shows also that 72 hr deprivation increased extinction responding under both conditions to a much

Fig. 4. Extinction response rates under the two S^Δ conditions plotted as a function of VI response rates under the three deprivation times. The rates are based upon the total number of sessions under each condition as shown in Table 1.

Table 2

Extinction response rates per second for the three deprivation periods with tone and the white keylight as S^A. The absolute and percentage increases are calculated with 24 hr as the base period.

Subject	Tone			White Keylight		
	Hr of Deprivation			Hr of Deprivation		
	24	48	72	24	48	72
P16	0.375	0.464	0.636	0.018	0.022	0.063
P20	0.208	0.251	0.362	0.034	0.048	0.106
P21	0.119	0.181	0.197	0.029	0.067	0.093
P30	0.275	0.256	0.392	0.037	0.039	0.089
$\bar{X}$	0.244	0.288	0.397	0.030	0.044	0.088
Absolute increase		0.044	0.153		0.014	0.058
% increase		18.0	62.7		46.7	193.3

greater extent than 48 hr deprivation. On the average, the increase in responding under both S^As was approximately four times as great for 72 versus 24 hr as for 48 versus 24 hr, in both relative and absolute terms.

Table 3 presents response rates under S^D and S^A in each phase of the experiment. These data show that the main effect observed in Figures 2 and 3, *i.e.*, the interaction between deprivation effects and discriminative accuracy, was also evident within each phase. Each bird showed improvement in discrimination with tone as S^A over the course of the experiment, indicating that improvement in stimulus

control can occur over a very long time period when the discrimination is difficult. Each of the birds had been exposed to the tone discrimination for at least 154 sessions before Phase 3 (see Table 1).

GENERAL DISCUSSION

The results of both experiments demonstrate the importance of stimulus control in determining the effects of other variables upon behavior in successive discrimination problems. The results of Experiment 1 support the idea that the degree of stimulus control that

Table 3

Response rates per second during each phase of Experiment 2. The number of sessions upon which these means are based is shown in Table 1.

Subject	Hr of Dep	Phase 1			Phase 2				Phase 3	
		VI	Tone	White K-L	VI-Tone		VI-White K-L		VI	Tone
P16	24	2.28	0.55	0.01	2.13	0.39	2.29	0.02	2.27	0.31
	48	2.25	0.85	0.02	1.99	0.48	2.05	0.02	2.07	0.30
	72	2.27	0.87	0.02	2.15	0.62	2.24	0.08	2.25	0.56
P20	24	2.70	0.25	0.06	2.44	0.25	2.52	0.03	2.39	0.14
	48	2.62	0.40	0.10	2.47	0.23	2.48	0.02	2.38	0.19
	72	2.64	0.39	0.12	2.56	0.47	2.61	0.10	2.46	0.23
P21	24	1.03	0.18	0.05	1.01	0.14	1.03	0.02	0.99	0.06
	48	1.00	0.14	0.09	1.01	0.19	1.01	0.06	1.06	0.20
	72	0.99	0.28	0.07	0.99	0.24	0.99	0.10	1.03	0.13
P30	24	0.87	0.30	0.04	0.78	0.34	0.81	0.04	0.77	0.20
	48	1.04	0.37	0.05	0.84	0.31	0.87	0.03	0.87	0.17
	72	1.14	0.46	0.09	0.88	0.43	0.86	0.09	0.89	0.33

exists will be a major determinant of the type of interaction that takes place between multiple schedule components, as other variables are manipulated (Wertheim, 1965; Pear and Wilkie, 1971). However, Pear and Wilkie's speculation that strong stimulus control would produce contrast while weak stimulus control would produce induction, was supported only for the latter case. There was no interaction when stimulus control was strong. Terrace (1963) also reported an absence of contrast under his procedure for errorless discrimination training, which is clearly an example of strong stimulus control.

Part of the problem may be that descriptions of stimulus control as either strong or weak are simply too broad to be useful. For example, calculation of discrimination ratios for each bird shows that when the white keylight was S^A, mean ratios over each of the five reinforcement cycles ranged from 0.99 to 1.00 for Bird 42 and from 0.95 to 0.99 for Bird 50. When tone was S^A, discrimination ratios ranged from 0.80 to 0.88 for Bird 42 and from 0.67 to 0.83 for Bird 50. It is conceivable, therefore, that a different type of interaction, *i.e.*, contrast, may have occurred at a level of stimulus control intermediate to the two substantially different levels achieved.

It is also possible that the method employed to change responding in one schedule component will interact with stimulus control in determining how responding is changed in the other components. For example, there have been two experiments in which the response rate in the variable component was altered, while response rate under a VI schedule was studied in the constant component, and obtained rates of reinforcement were equal in both components. Brownstein and Hughes (1970) added a signalling procedure to the variable component so that the keylight was on only when responding would be reinforced in that component. Responding in the variable component decreased under this procedure while responding increased in the constant component; an example of positive behavioral contrast. Hemmes and Eckerman (1972) initially employed a *mult* VI-VI schedule that was changed so that one component was replaced by a schedule that differentially reinforced high rates of responding (DRH). This resulted in a maintained increase in rate of responding during both the constant (VI) and varied

(DRH) components; an example of positive induction. Since both experiments employed a VI schedule in the constant component, one could assume that stimulus control was equal, yet one procedure resulted in contrast while the other produced induction. Terrace (1966) suggested that an increased rate of responding in the constant component may result from increased "aversiveness" in the variable component. Hemmes and Eckerman (1972) acknowledged that the DRH schedule that they employed may have been aversive, and it has been demonstrated that increasing the response requirement is aversive because it elicits aggressive behavior (Cherek and Pickens, 1970).

An explanation based upon "aversiveness" is congruent with the results of Hemmes and Eckerman (1972), as well as those of Powell (1971a), who found an increase in responding in the constant component when responding was suppressed by punishment shock in the variable component. However, since extinction also appears to have aversive properties (Azrin, Hutchinson, and Hake, 1966; Thompson and Bloom, 1966), it fails to explain the results of Experiment 1, since increased aversiveness in the form of an extinction contingency did not result in increased responding in the constant component.

Experiment 2 replicates and extends the recent finding (Powell, 1971b) that the existing level of stimulus control interacts with motivational factors arising from deprivation in determining the accuracy of performance in a successive discrimination task. The higher the level of stimulus control attained, the smaller the decrease in discriminative accuracy as deprivation increases. The present results suggest that this interaction is exponential in nature, rather than simply multiplicative, for increases in S^A responding were four times as great from 24 to 72 hr of deprivation as from 24 to 48 hr, under conditions of both high and low stimulus control.

There was no evidence of interaction between schedule components in Experiment 2. For three of the four birds, response rates in S^P were fairly stable throughout the experiment, while responding in S^A increased as deprivation increased. Several recent studies have found VI response rates to be relatively insensitive to deprivation in animals with extensive training (Powell, 1971b, 1971c). Ferster and

Skinner (1957) also observed that two of four pigeons showed no consistent relationship between deprivation and VI response rate.

In both experiments, strong and weak stimulus control were usually correlated with visual and auditory stimuli, respectively, raising the question of procedural confounding. To my knowledge, there has been no suggestion arising from the large number of studies involving schedule interaction that sensory modality *per se* affects the type of interaction. Also, there is evidence in the individual performances here and in the earlier experiment (Powell, 1971a) that sensory modality is not a factor. In Experiment 2 here, auditory stimulus control was strongest for Pigeon 20 and increases in deprivation had less effect upon discriminative accuracy for this bird than for Pigeons 16 and 21 (Figure 3). Similarly, where auditory stimulus control was strong in the previous study (Powell, 1971a) deprivation did not affect discrimination (Pigeon 29, p 102), while weak control with visual stimuli resulted in deprivation having a marked effect upon discriminative accuracy (Pigeon 17, p. 99). Thus, stimulus control, apart from sensory modality, seems to be the critical factor.

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