*DIFFERENTIAL AUTOSHAPING TO COMMON AND
DISTINCTIVE ELEMENTS OF POSITIVE AND
NEGATIVE DISCRIMINATIVE STIMULI¹*

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The learning by hungry pigeons of a discrimination between two successively presented compound visual stimuli was investigated using a two-key autoshaping procedure. Common and distinctive stimulus elements were simultaneously presented on separate keys and either followed by food delivery, S+, or not, S-. The subjects acquired both between-trial and within-trial discriminations. On S+ trials, pigeons pecked the distinctive stimulus more than the common stimulus; before responding ceased on S- trials, they pecked the common stimulus more than the distinctive one. Mastery of the within-display discrimination during S+ trials preceded mastery of the between-trials discrimination. These findings extend the Jenkins-Sainsbury analysis of discriminations based upon a single distinguishing feature to discriminations in which common and distinctive elements are associated with both the positive and negative discriminative stimuli. The similarity of these findings to other effects found in autoshaping—approach to signals that forecast reinforcement and withdrawal from signals that forecast nonreinforcement—is also discussed.

Much of what is known about the way organisms learn successive discriminations has come from the key pecking of different visual patterns by hungry pigeons (see Terrace, 1966 for a general review). Ordinarily, the shared and unique aspects of those visual stimuli are simultaneously projected on a single stimulus-response device. Recently, however, differential responding to the common and distinctive elements of compound visual stimuli has been measured either by projecting the stimulus elements upon different response keys (Jenkins, 1973; Jenkins and Sainsbury, 1969, 1970; Sainsbury, 1971) or by rapidly alternating those elements upon a single manipulandum (Farthing, 1971). Use of these methods permits the direct measurement of selective stimulus control, rather than relying upon more indirect measures such as transfer or generalization tests (see Sutherland and Mackintosh, 1971).

Most of this recent work has been concerned with discriminations based upon a single distinguishing element or feature. In the so-called "feature-positive" (FP) condition, a unique stimulus element is correlated with reinforcer presentation. For example, S+ might be composed of a white dot and a red dot projected on a small dark field and S- might be composed of two white dots. In the "feature-negative" (FN) condition, the stimulus-reinforcer relations of the two-dot displays would be reversed. Despite the fact that FP and FN discriminations involve the same physical stimuli, the former discrimination is mastered much more rapidly than the latter, which may not be mastered at all (e.g., Jenkins and Sainsbury, 1969).

A clue as to why the formation of a successive discrimination may depend upon assigning the distinctive feature to S+ or S- trials is revealed by examining the portion of the displays to which subjects respond. In the case of the FP discrimination, responding comes to be directed toward the distinctive feature on S+ trials before responding on S- trials eventually ceases. In the case of the FN discrimination, responding shifts away from the distinctive feature on S- trials; however, pecking at the remainder of the S- display continues, leading to the failure of a successive discrimination to emerge.

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Table 1

Types of compound stimuli on S+ and S- trials in two-key symmetrical and asymmetrical discriminations. The numbers in parentheses next to the color of each response key indicate the overall probability of reinforcement in the presence of stimuli of that element class. Italicized key colors indicate those to which responding should be confined at asymptote.

<i>Asymmetrical</i>									<i>Symmetrical</i>			
	<i>FP(R)</i>		<i>FP(G)</i>		<i>FN(R)</i>		<i>FN(G)</i>		<i>(R/G)</i>		<i>(G/R)</i>	
S+	W(0.50)	R(1.00)	W(0.50)	G(1.00)	W(0.50)	W(0.50)	W(0.50)	W(0.50)	W(0.50)	R(1.00)	W(0.50)	G(1.00)
S−	W(0.50)	W(0.50)	W(0.50)	W(0.50)	W(0.50)	R(0.00)	W(0.50)	G(0.00)	W(0.50)	G(0.00)	W(0.50)	R(0.00)

These findings indicate that subjects in both FP and FN conditions concentrate their pecking at that portion of the displays that has the highest positive correlation with the reinforcer—the feature in the former case and some common trial element in the latter. They further indicate that changes in response strength are more quickly evidenced within trials than between trials (see Jenkins and Sainsbury, 1969, 1970, and Wasserman, 1974 for further discussion of these and related findings).

This view of responding under FP and FN conditions is more completely specified in Table 1. The first four columns detail the correlation with the reinforcer of each class of stimulus element in FP and FN conditions, with the color of the distinctive feature (red or green) counterbalanced. Probabilities were assigned by noting the probability of reinforcement given the presence of a single key color, irrespective of other concurrently presented key colors. Also included are the asymptotic performances of subjects in the FP and FN arrangements based upon the assumptions that (a) subjects view the compound stimuli as disjunct displays rather than as holistic patterns, and (b) subjects respond to that stimulus element class most positively correlated with reinforcement.

In their original work, Jenkins and Sainsbury (1969) suggested that an analysis based upon the concepts of distinctive and common elements may aid in understanding the learning of discriminations in which S+ and S- possess both shared and unique elements. Considered in this light, examining discriminations based upon a single distinctive feature ought to allow a synthetic treatment of more complicated forms of discrimination learning. That was the intent of the present study.

One approach to a classification of discrimination problems was provided by Jenkins and

Sainsbury (1970). According to this formulation, discriminative stimuli are said to differ from one another in one of two ways. *Asymmetrically* different discriminative stimuli are those in which the class or classes of elements in one are completely comprised by the other. Thus, the display two white dots (WW) and the display a white dot and a red one (WR) are asymmetrically different (see Table 1). "White dot" is an element common to WW and WR; furthermore, the class of elements in WW ("white dot") is completely comprised by the WR display. *Symmetrically* different discriminative stimuli are those in which the class or classes of elements in each are not completely comprised by the other. For instance, the displays WR and WG share the common element "white dot". However, the element class "red dot" is unique to WR and the element class "green dot" is unique to WG. Therefore, both of the element classes in one compound stimulus are not comprised by the other compound stimulus. The last two columns of Table 1 give two examples of symmetrically different discriminative stimuli.

Extension of the Jenkins and Sainsbury work on discrimination learning with asymmetrically different discriminative stimuli to the learning of discriminations based upon symmetrically different discriminative stimuli suggests the following: (a) The successive discrimination should be readily mastered. (b) Discriminative responding should be observed to the distinctive stimulus on S+ trials and to the common stimulus on S- trials, before the successive discrimination is mastered. (c) Responding should occur only to the distinctive feature on S+ trials at asymptote (see Table 1).

The present experiment studied the symmetrical discriminations shown in the last two columns of Table 1. Two compound stimulus displays were successively presented. A com-

mon stimulus (*c*) was presented on all trials and one of two different stimuli was correlated with reinforcer presentation (*d*+) while the other was correlated with extinction (*d*-). Two pecking keys in conventional conditioning chambers were used for stimulus presentation. As these keys were relatively far apart, discriminative responding within trials to the stimulus elements should be maximized (Sainsbury, 1971). Finally, the present experiment evoked and maintained key pecking by means of the autoshaping procedure (Brown and Jenkins, 1968, Experiment 4) in which delivery of food was never contingent on responding. This paradigm was selected in order to determine whether the response-dependent schedules of reinforcement used in previous studies were necessary for reliable within-trial and between-trial discrimination learning.

METHOD

Subjects

Twelve experimentally naive adult homing pigeons, reduced to 75% of their free-feeding weights, were housed individually with water constantly available in the home cages.

Apparatus

Two identical three-key Lehigh Valley Electronic pigeon test chambers were used. Directly above and below the center key were the houselight and the grain tray, respectively. The 2.6-cm diameter left and center pecking keys (the right key was covered and not used) were 8.5 cm apart and required 10 g (0.10 N) for activation. Each key could be illuminated with white, green, or red light by means of a tricolor "Q" lamp outfitted with ESB 24 bulbs. White noise was continuously sounded from a small loudspeaker just to the left of the grain tray in order to mask extraneous sounds produced by the scheduling and recording equipment located in an adjoining room.

Procedure

First, the pigeons were trained to approach and eat quickly from the grain tray. The birds were individually placed in an illuminated test chamber with the tray elevated, lighted, and filled to the brim with grain. After the bird had eaten for about 20 sec, the tray was lowered. From then on, the grain tray was elevated for 3 sec at irregular intervals. If the

pigeon did not feed from the tray after three consecutive presentations, the tray remained elevated until the pigeon had eaten for 3 sec. Tray training continued until each bird had efficiently eaten grain on a total of twenty 3-sec tray presentations.

Experimental training began the following day. Each of 64 daily trials involved illumination of the left and center keys for 7 sec, followed immediately by 3 sec of access to grain in the lighted tray if a reinforcer were scheduled on that trial. The onsets of successive trials were separated by intertrial intervals of 50 sec. The houselight was continuously illuminated throughout all experimental sessions (see Wasserman, 1973*b*). Key pecks were recorded but had no effect upon the scheduled stimuli and reinforcers.

Six pigeons were randomly assigned to each of two treatment conditions differentiated on the basis of the color of *d*+ and *d*- features. For both training conditions, one key was white-illuminated on every trial (*c*). The other key was alternately illuminated either red or green on half of the trials. For birds in Group G/R, green was designated *d*+ and red was designated *d*-; for birds in Group R/G, red was designated *d*+ and green was designated *d*-. The *cd*+ trials always involved a food reinforcer; *cd*- trials never involved food. The sequence of stimulus and reinforcer presentations was random with the limitations that (a) no more than three *cd*+ or *cd*- trials could occur in succession and (b) no keylight stimulus (white, green, or red) could appear on the left or the center key more than three times in a row. Training lasted six days.

RESULTS

By the end of the first trial block (32 trials) 11 of the 12 pigeons had begun key pecking, and by the end of the second trial block all had done so. By the end of the second trial block, all 12 birds had pecked each of the four stimulus elements of the compound stimulus displays; *c*+ and *d*+ on *cd*+ trials and *c*- and *d*- on *cd*- trials. An indication of the distribution of responding to the stimulus elements can be seen in Figure 1. In Group R/G, responding to *d*+ quickly rose to high levels, whereas responding to the other stimulus elements at first rose but then declined to virtually zero by the end of the first four trial blocks. In Group

Fig. 1. Median number of total pecks to $c+$ and $d+$ stimuli on $cd+$ trials and to $c-$ and $d-$ stimuli on $cd-$ trials. Trial blocks were composed of 32 trials each. Group R/G had red as $d+$ and green as $d-$; Group G/R had green as $d+$ and red as $d-$.

G/R, it took longer for $d+$ to become the most-responded-to stimulus element (R/G = median of 2.0 trial blocks, G/R = median of 4.5 trial blocks; $U = 1.5$, $p < 0.01$).² After an initial increase, responding to $c+$, $c-$, and $d-$ stimuli decreased to near zero and remained there on Days 5 and 6 of training. Overall c responding in Group G/R exceeded overall c responding in Group R/G ($U = 1$, $p < 0.01$).

These changes in responding to the four stimulus elements influenced both between-trial and within-trial discriminations.³ Considering successive between-trial performance with the formula $cd+/(cd+ + cd-)$, the 0.90

discrimination criterion was reached sooner by R/G birds than G/R birds (R/G = median of 4.0 trial blocks, G/R = median of 6.0 trial blocks; $U = 4$, $p < 0.05$). A similar superiority of Group R/G over Group G/R held when selective responding within $cd+$ trials was assessed according to the formula $d+/(d+ + c+)$. Group R/G met the 0.90 criterion in a median of 2.5 trial blocks, whereas a median of 5.0 trial blocks was required by Group G/R ($U = 1.5$, $p < 0.01$). The distributions of responding to each stimulus element of all 12 subjects on within-trial and between-trial criterion blocks are shown in Tables 2 and 3, respectively.

Discriminative performance within trials preceded discriminative performance between trials. Considering that trial block on which

²All reported p values are based on two-tailed tests.

³Only trial blocks containing 10 or more key pecks were considered here.

Table 2

Total key pecks to stimulus elements in trial block first reaching the 0.90 $d+/(d+ + c+)$ criterion.

Subject	Trial Block	$\frac{d+}{(d+ + c+)}$	c+	c-	d+	d-
GROUP R/G						
215	1	0.94	2	4	31	2
216	2	0.91	7	40	74	14
221	2	0.98	1	14	57	1
222	3	1.00	0	9	29	3
V	3	0.94	7	56	114	24
W	3	1.00	0	23	25	0
GROUP G/R						
220	3	0.90	7	49	66	5
225	4	1.00	0	42	120	0
132	6	0.94	13	32	217	0
126	9	0.96	2	20	54	0
S	4	0.95	3	12	55	0
150	7	1.00	0	26	99	7

the $d+/(d+ + c+)$ discrimination first reached the 0.90 criterion, the corresponding median within-display *versus* between-display discriminations for Group R/G and Group G/R were 0.96 *versus* 0.66 and 0.96 *versus* 0.74, respectively. The superior within-display than between-display discriminations at that point were representative of all 12 pigeons ($p < 0.01$, sign test).

Finally, discriminative performance to the stimulus elements was observed during both $cd+$ trials and $cd-$ trials. Across G/R and R/G conditions, 10 of 12 pigeons pecked $d+$ more than $c+$ overall ($p < 0.05$, sign test) and

Table 3

Total key pecks to stimulus elements in trial block first reaching the 0.90 $cd+/(cd+ + cd-)$ criterion.

Subject	Trial Block	$\frac{cd+}{(cd+ + cd-)}$	c+	c-	d+	d-
GROUP R/G						
215	4	1.00	0	0	157	0
216	4	0.99	0	1	134	0
221	3	0.98	1	1	165	2
222	4	0.94	0	2	59	2
V	4	0.96	1	10	140	6
W	5	0.97	0	2	72	0
GROUP G/R						
220	4	0.91	0	10	151	5
225	5	0.99	1	1	163	0
132	7	0.92	19	21	216	0
126	10	1.00	0	0	87	0
S	5	0.91	2	12	116	0
150	8	1.00	0	0	150	0

the same number pecked $c-$ more than $d-$ overall.

DISCUSSION

The present findings indicate that differential responding does emerge to the common and distinctive elements of symmetrically different discriminative stimuli. Specifically, responding converged upon the distinctive element of $S+$ and upon the common element of $S-$ before responding to $S-$ eventually ceased.

These results, along with those of Jenkins and Sainsbury (1969, 1970; Jenkins, 1973; Sainsbury, 1971) and Farthing (1971), provide strong support for an analysis of discrimination learning based upon common and distinctive elements. Although the present experiment involved *symmetrically* different discriminative stimuli, discrimination learning was in accordance with principles derived from discriminations formed between *asymmetrically* different discriminative stimuli. Future research into the generality of this approach is clearly warranted.

Unlike previous studies, the present experiment used an autoshaping procedure to generate and sustain key pecking. Other work in autoshaping has revealed that behavior directed toward the stimulus most highly correlated with reinforcement will ordinarily arise if the stimulus is easily localized (*e.g.*, Allaway, 1971; Bilbrey and Winokur, 1973; Brown and Jenkins, 1968; Gamzu and Schwartz, 1973; Gamzu and Williams, 1971, 1973; Jenkins and Boakes, 1973; Peterson, Ackil, Frommer, and Hearst, 1972; Schwartz, 1973; Wasserman, 1973a, b, 1974; Wasserman, Franklin, and Hearst, 1974; Wasserman and McCracken, 1974). Furthermore, behaviors directed away from a localized stimulus signalling nonreinforcement may also arise in autoshaping studies (see Jenkins and Boakes, 1973; Wasserman *et al.*, 1974). These autoshaping findings correspond closely with those of operant discrimination studies in which "feature-positive" subjects peck at the distinctive feature and "feature-negative" subjects peck away from it. They also parallel the findings of the present study in which individual subjects pecked at the distinctive feature of a compound stimulus that signalled reinforcer delivery but pecked away from the distinctive feature of a different compound stimulus that signalled extinction

(see also Jenkins and Boakes, 1973 where an observing response procedure suggests a similar conclusion). Parallels such as these point to a common behavioral mechanism underlying autoshaping and several aspects of operant discrimination learning (E. Hearst and H. M. Jenkins, personal communication).

Finally, the present results indicate that assignment of the two key colors to S+ and S- had a significant influence upon the speed of acquisition of the successive discrimination as well as affecting the distribution of responding to common and distinctive elements of the compound stimuli. A similar result is found in discriminations formed on the basis of a single distinguishing feature and may be due to the greater "salience" of one stimulus than another (see Jenkins, 1973).

REFERENCES

- Allaway, T. A. *Attention, information, and auto-shaping*. Unpublished doctoral dissertation, University of Pennsylvania, 1971.
- Bilbrey, J. and Winokur, S. Controls for and constraints on autoshaping. *Journal of the Experimental Analysis of Behavior*, 1973, 20, 323-332.
- Brown, P. L. and Jenkins, H. M. Auto-shaping of the pigeon's key peck. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 1-8.
- Farthing, G. W. Discrimination of compound stimuli involving the presence or absence of a distinctive visual feature. *Journal of the Experimental Analysis of Behavior*, 1971, 16, 327-336.
- Gamzu, E. and Schwartz, B. The maintenance of key pecking by stimulus-contingent and response-independent food presentation. *Journal of the Experimental Analysis of Behavior*, 1973, 19, 65-72.
- Gamzu, E. and Williams, D. R. Classical conditioning of a complex skeletal response. *Science*, 1971, 171, 923-925.
- Gamzu, E. R. and Williams, D. R. Associative factors underlying the pigeon's key pecking in autoshaping procedures. *Journal of the Experimental Analysis of Behavior*, 1973, 19, 225-232.
- Jenkins, H. M. Noticing and responding in a discrimination based on a distinguishing element. *Learning and Motivation*, 1973, 4, 115-137.
- Jenkins, H. M. and Boakes, R. A. Observing stimulus sources that signal food or no food. *Journal of the Experimental Analysis of Behavior*, 1973, 20, 197-207.
- Jenkins, H. M. and Sainsbury, R. S. The development of stimulus control through differential reinforcement. In N. J. Mackintosh and W. K. Honig (Eds.), *Fundamental issues in associative learning*. Halifax: Dalhousie University Press, 1969. Pp. 123-161.
- Jenkins, H. M. and Sainsbury, R. S. Discrimination learning with the distinctive feature on positive or negative trials. In D. I. Mostofsky (Ed.), *Attention: contemporary theory and analysis*. New York: Appleton-Century-Crofts, 1970. Pp. 239-273.
- Peterson, G. B., Ackil, J. E., Frommer, G. P., and Hearst, E. S. Conditioned approach and contact behavior towards signals for food or brain-stimulation reinforcement. *Science*, 1972, 177, 1009-1011.
- Sainsbury, R. S. Effect of proximity of elements on the feature-positive effect. *Journal of the Experimental Analysis of Behavior*, 1971, 16, 315-325.
- Schwartz, B. Maintenance of key pecking by response-independent food presentation: the role of the modality of the signal for food. *Journal of the Experimental Analysis of Behavior*, 1973, 20, 17-22.
- Sutherland, N. S. and Mackintosh, N. J. *Mechanisms of animal discrimination learning*. New York: Academic Press, 1971.
- Terrace, H. S. Stimulus control. In W. K. Honig (Ed.), *Operant behavior: areas of research and application*. New York: Appleton-Century-Crofts, 1966. Pp. 271-344.
- Wasserman, E. A. Pavlovian conditioning with heat reinforcement produces stimulus-directed pecking in chicks. *Science*, 1973, 181, 875-877. (a)
- Wasserman, E. A. The effect of redundant contextual stimuli on autoshaping the pigeon's keypeck. *Animal Learning and Behavior*, 1973, 1, 198-206. (b)
- Wasserman, E. A. Stimulus-reinforcer predictiveness and selective discrimination learning in pigeons. *Journal of Experimental Psychology*, 1974, 103, 284-297.
- Wasserman, E. A., Franklin, S. R., and Hearst, E. Pavlovian appetitive contingencies and approach vs. withdrawal to conditioned stimuli in pigeons. *Journal of Comparative and Physiological Psychology*, 1974, 86, 616-627.
- Wasserman, E. A. and McCracken, S. B. The disruption of autoshaped key pecking in the pigeon by food-tray illumination. *Journal of the Experimental Analysis of Behavior*, 1974, 22, 39-45.

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