chapter 9
Perceptual Learning:

Association and Differentiation

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An animal (or person) trained to respond in a given way to one stimulus will tend to show the same behavior (although usually with reduced vigor) when confronted with another similar stimulus. The standard explanation for this phenomenon of generalization is, in principle, very simple. It is acknowledged that the event or object that the experimenter refers to, for convenience, as a stimulus will always be, in fact, a complex made up of many features or elements. The simplest of tones, such as might be used in the animal conditioning laboratory, has a definable intensity, duration, frequency, site of origin, and so on. All of these features may be presumed to be capable of entering into associations and thus of contributing to a conditioned response (CR) that the tone can come to elicit as a result of training. Another stimulus such as a clicker may appear to be quite different from the tone but it will hold

some features in common with the latter. The situation is shown in Fig. 9.1. Each circle represents the set of features that constitutes a stimulus. Each of the stimuli, A and B, possesses certain unique and defining features (represented by the areas marked a and b). However, A and B also have some

features in common (the overlapping area marked c). Establishing a CR to A will mean conditioning both a and c elements. Generalization to B will occur because presentation of this stimulus will activate some elements (the c elements) that have been conditioned when presented as parts of Stimulus A.
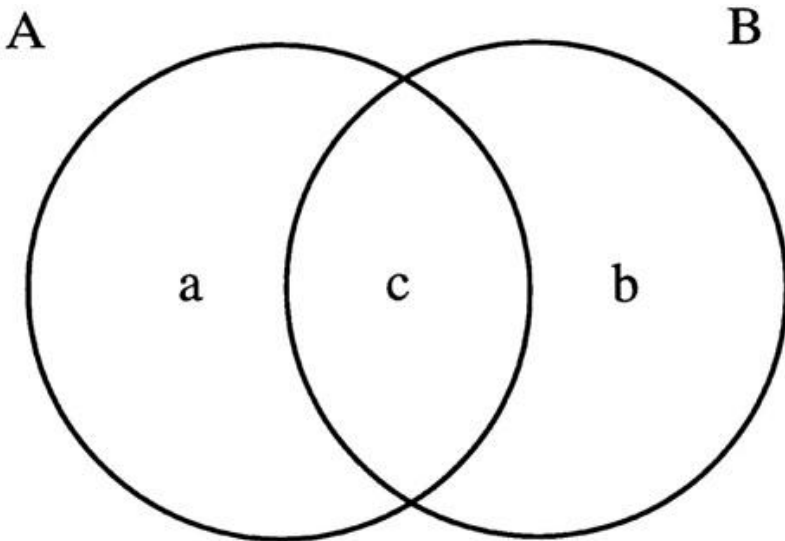
A   B

a   c   b

FIG. 9.1. Diagrammatic representation of two stimuli, A and B. The area of the circle represents the set of stimulus elements activated by a stimulus. Those in the segment marked a are elements unique to Stimulus A; those in the b segment are unique to B. The area marked c corresponds to a set of elements held in common by the two stimuli.

The degree to which generalization occurs between a pair of stimuli can be modified by prior experience of them. Some forms of prior training can enhance generalization; others can reduce it (i.e., enhance the ease with which the two stimuli are

discriminated), resulting in what has sometimes been termed a perceptual learning effect. There is nothing in what has been said so far about the nature of generalization that would lead us to expect this. If the set of elements activated by a given stimulus is fixed and defined by the nature of that stimulus, and if our conditioning procedures are effective in endowing its elements with associative strength, then it might be supposed that generalization to

some other stimulus would occur automatically, to a degree determined solely by the number of elements held in common. The fact that prior experience with the stimuli can influence the extent to which generalization will occur needs explanation. Certain possibilities come to mind immediately. Some are consistent with the framework just outlined—pretraining procedures might have their effects because they modulate the associative strength acquired by common elements or because they establish other associations that also contribute to the strength of the observed CR. Other possibilities may require a more radical revision of the framework—perhaps we are wrong to take the set of elements evoked by a stimulus as a given; perhaps the constituents of this set vary as a result of experience. The essence of the notion of stimulus differentiation, as employed by Gibson (1969) in her influential account of perceptual learning, is that, with experience, events or objects become able to activate the central representations of elements that were not activated on first presentation; also that some elements (principally those that are not unique features of the stimulus) may become less readily activated.

In what follows I attempt a review of the major categories of procedure in which generalization (or discrimination) has been shown to be modulated by prior training in animal

subjects. For convenience of exposition I divide these procedures into two main groups—those in which pretraining is given with just one of the critical stimuli (i.e., just to A, the reinforced stimulus, or just to B, the test stimulus) and those in which pretraining is given to both. Each of these sections is further subdivided according to whether the pretraining involves reinforcement or not. The central question in each case is whether the phenomena can be accommodated by amendments to associative theory as applied to the framework depicted in Fig. 9.1, or whether a more radical revision, which might involve the operation of a special process of perceptual learning, needs to be accepted. The topics to be discussed were considered in detail by Hall (1991), who dealt with the work published before 1990. Only an outline of the conclusions reached then is presented here, and the focus is on research conducted since that date.

Pretraining with One Stimulus

Reinforced Training With Stimulus A

A test of generalization requires that A receive some reinforced training to establish the response under study. However, we may compare the generalization produced by a standard amount of initial training with
that obtained after more extensive reinforced training with A. Extended training can be expected to ensure that all the elements of A, both type a and type c will become strongly associated with the reinforcer. If no other processes are operating, generalization to B should occur readily and be more marked than that obtained when less training with A is given. It is of interest, therefore, that it has been repeatedly

reported that, in some training preparations, generalization gradients appear to grow sharper after prolonged initial training (e.g., Hearst & Koresko, 1968; Hoffeld, 1962; Hovland, 1937). This result prompts the speculation that prolonged exposure to Stimulus A might allow differentiation to occur, with the stimulus becoming increasingly likely to activate a elements, and the c elements becoming unresponsive. If the presentation of B on test is also unable to activate the c elements fully, then generalized responding will be weak. An obvious problem for this account is that it is difficult to see how the system could "know" which elements were the c elements, in advance of experience with test stimulus B. I do not consider possible solutions to this problem at this stage, however, in view of other, more basic issues that arise in connection with these data.

First, at the empirical level, there is the mundane point that the sharpening of the gradient observed in at least some experiments may be more apparent than real. Generalization gradients are often expressed in relative terms (i.e., the responding shown to B is given as a proportion of that shown to A). Extended reinforcement of A can thus produce a sharpening of the relative gradient not because of any real reduction in the vigor of the response elicited by B, but because it produces a disproportionate increase in the vigor of that evoked by A. Even for those few cases in which there appears to be a sharpening of the gradient when measured in absolute terms, it is possible to construct a perfectly adequate alternative account without departing from the tenets of standard associative learning theory. When a subject is first reinforced in the presence of A, other aspects of the training situation will also acquire associative strength and will thus be able to contribute to the responding shown to B on test.

However, standard associative learning principles (e.g., Rescorla & Wagner, 1972) predict that these background cues, being less well correlated with reinforcement than Stimulus A, will lose strength as training proceeds. This loss may be enough to explain why the response to the test stimulus, B, should be reduced.

We must conclude, then, that the classical body of work on simple generalization provides only weak support for the notion that stimulus differentiation goes on during extended training, and recent work using this procedure has done little to change the picture (see, e.g., Walker & Branch, 1998). There are, however, some recent experiments, using a rather different procedure and directed, ostensibly, at a rather different issue, that turn out to be relevant to the basic theoretical question.

Todd and Mackintosh (1990) trained pigeons on a successive discrimination in which, on every session, the birds saw 20 pictorial stimuli, each presented twice, usually several trials apart. The birds were given a recognition memory task in that they were rewarded for pecking at a picture on its first presentation but not on the second. There were two conditions of training. In one, the same pictures were used on every session, and thus a relative recency discrimination was required—all the pictures were familiar and the bird's job was to refrain from pecking at a picture that it had seen earlier in the same session. In the other, the absolute novelty version of the task, a new set of pictures was used on each session so that the bird could solve the problem simply by pecking at any picture that it had never seen before. Rather surprisingly, given that proactive interference effects might be expected to disrupt performance on the relative recency discrimination, Todd and Mackintosh found that this version of the task was

learned more readily than the absolute novelty discrimination. (This result has been confirmed and extended by Macphail, Good, & Honey, 1995, whose experimental results are presented in Fig. 9.2.) Todd and Mackintosh concluded that any proactive interference effects occurring in their experiment must have been outweighed by the operation of another, more powerful process.

The relevance of these experiments to the issue of the effect of extended training on generalization is as follows. First, an important feature of the relative recency task is that the subjects are faced with the same set of stimuli on every session and thus can become fully familiar with them; to this extent, the relative recency task constitutes a parallel to the extended training procedure. Second, generalization between the stimuli used will play an important part in determining the outcome. Accurate performance depends not only on an ability to recognize a picture as being the same as one seen before, but also on the ability to discriminate this picture from others that are similar but not identical—a reduction in the tendency to generalize between similar pictures would facilitate performance. The superior performance of subjects in the relative recency condition can thus be taken to support the view that generalization gradients are sharpened after extensive training. This is essentially the conclusion reached by Todd and Mackintosh (1990), who argued that repeated exposure to a stimulus will be needed if the birds are to acquire "a representation of the stimulus … sufficiently precise and durable for it to be discriminated from the numerous other stimuli to which the birds are being exposed" (p. 398). Proactive interference effects in the relative recency condition, they suggested, are outweighed by the operation of the perceptual learning processes that result in the formation

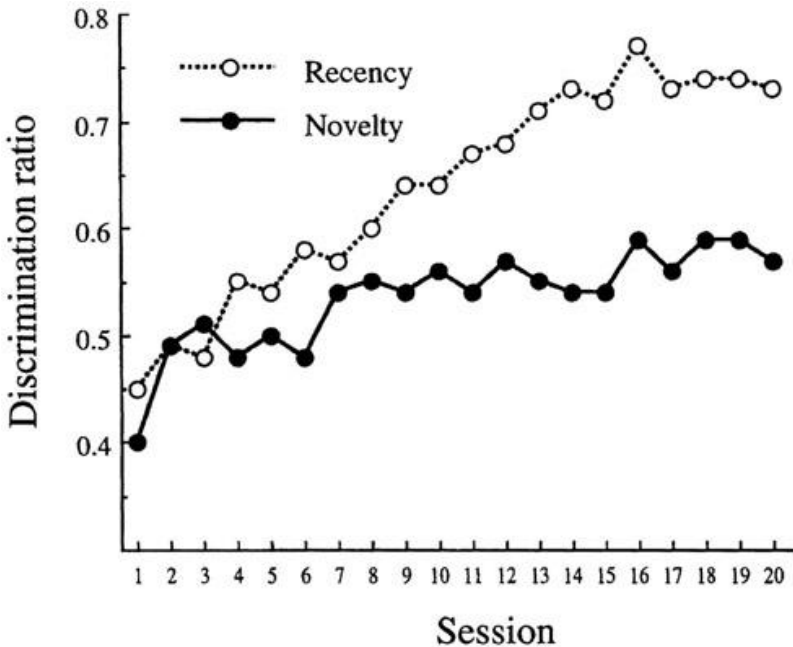of such representations. Their results do not speak, however, to the exact nature of the process involved.

FIG. 9.2. Mean discrimination ratios (ratio of responses in the first 10 sec of positive trials to responses in the first 10 sec of all trials) over 20 days of training for two groups of pigeons in the experiment by Macphail et al. (1995). All animals saw 12 pictures twice on each session and were rewarded for responding to the first presentation of a picture. In the recency condition the same pictures were used in every session; in the novelty condition a new set of pictures was used in each session.

Nonreinforced Preexposure to Stimulus A

When reinforcement is given during preexposure to A, effects based simply on the animal's growing familiarity with this stimulus are likely to be obscured by the enhanced generalization that will be a consequence of A's elevated level of associative strength. It may seem sensible, then, to look at the effects of nonreinforced preexposure to A. Does this procedure result in reduced generalization to B once a CR has subsequently been established to A? Unfortunately, this question yields no simple answer—some experiments (e.g., Honey, 1990, Experiment 1) have found generalization to be reduced; others (e.g., Symonds & Hall, 1995, Experiment 1) have found no difference between subjects given preexposure to A and those for whom A was novel at the time of conditioning. No doubt a close analysis of the procedural details of these experiments

would throw up suggestions about the source of this discrepancy, but to pursue such an analysis seems unlikely to be fruitful for the following reason. Whatever else may have happened during nonreinforced preexposure in the experiments just cited, we can be fairly sure that Stimulus A would have suffered latent inhibition and thus have been rendered less effective as a conditioned stimulus (CS) when it came to conditioning. This in itself would be enough to reduce the extent to which Stimulus B was capable of evoking generalized responding, thus rendering ambiguous the result of prime theoretical importance. Reduced generalization to B will be of interest only if we can be reasonably confident that the groups being compared do not differ in the associative strength acquired by A. The simple absence of a difference in a direct test of A will not be enough to convince (such a test

may simply be less sensitive than one given with Stimulus B). We should focus our attention, therefore, on the small group of experiments in which, in spite of what might expected from considerations of latent inhibition, preexposure to A has been found to facilitate conditioning with this stimulus.

These experiments are characterized by the fact that exposure to A, both during preexposure and on the conditioning trial, is kept to a minimum, and also by the use of stimuli substantially more complex than those usually employed in standard conditioning procedures. Thus, Bennett, Tremain, and Mackintosh (1996) conducted a flavor-aversion experiment with rats in which the CS was a solution of monosodium glutamate to which were added sucrose and quinine. Only 1 ml of the compound was given on the conditioning trial and preexposure consisted of a single presentation of 3 ml of the compound given several days before conditioning. On a test given after conditioning, animals given this preexposure showed a more substantial aversion than control subjects given no preexposure. The other experiments that revealed a similar facilitation of conditioning as a result of preexposure all used a context conditioning procedure in which the CS is the set of cues that constitute an experimental chamber and the CR is the freezing response that develops in rats that have received an electric shock in that chamber. In these experiments, by Fanselow (1990) and by Kiernan and Westbrook (1993), rats were given brief exposure to the context (for 2 min in Fanselow's experiments, for four 2-min trials in those by Kiernan & Westbrook) prior to a conditioning session in which a single shock was given after the rat had been in the context for about a minute. On a subsequent test session, these subjects showed more freezing in the context than did control subjects that had

received no preexposure (or preexposure to a different context).

Before turning to the issue of how the CR established by these training procedures generalizes to other stimuli, we should consider why it

might be that these procedures yield a facilitation of conditioning rather than the usual latent inhibition effect. The explanation offered in one form or another by all the experimenters supposes that preexposure allows the animal to form an integrated representation of the complex of features that will be used as the CS. With extended preexposure, latent inhibition will begin to develop, but before this happens (i.e., when preexposure is brief) the beneficial effects on conditioning of having a preformed representation can be observed. Bennett etal. (1996) referred to the formation of a representation as a process of unitization, and provided an associative account of the mechanism, based on that suggested by McLaren, Kaye, and Mackintosh (1989). Preexposure to a complex stimulus, they pointed out, allows the animal to experience the cooccurrence of its various features, and thus allows the formation of associative links among these features. On a subsequent, brief, conditioning trial, only some of these features will be sampled (the stimulus is complex and the animal's processing capacity is limited), and only these will become associated with the reinforcer. A different set may be sampled on the test trial but, for animals given preexposure, a CR should still occur as the associative links established during preexposure will mean that those sampled on test will be able to activate those that formed links with the reinforcer during conditioning. The basic explanatory principle will be familiar as a form of sensory preconditioning.

The issue of generalization in animals given minimal preexposure to A prior to conditioning was addressed by Kiernan and Westbrook (1993, Experiment 3; see also Killcross, Kiernan, Dwyer, & Westbrook, 1998, Experiments lb and 2). The experimental group in the Kiernan and Westbrook study received four 2-min preexposures to Context A followed by a conditioning session in which a shock was given 60 sec after the animals had been put into this same context. Control subjects experienced the same conditioning regime but received their preexposure in a different context, C. All subjects then received test sessions in which freezing was measured in A and also in the generalization test context, B. The results of this test are summarized in Fig. 9.3. The results for the test in A confirm those already discussed—the preexposed subjects showed significantly more freezing than did the controls. On the test in Context B, the levels of freezing were somewhat less, as might be expected of a generalization test. Critically, the pattern was now reversed with the control subjects showing more freezing than the experimental subjects.

The results presented in Fig. 9.3 show that nonreinforced preexposure to A can limit the degree of generalization to B. This effect is not to be explained away in terms of poor acquisition of strength by A—the preexposure procedure used was one that actually facilitated conditioning to A. The conclusion suggested by this pattern of results is
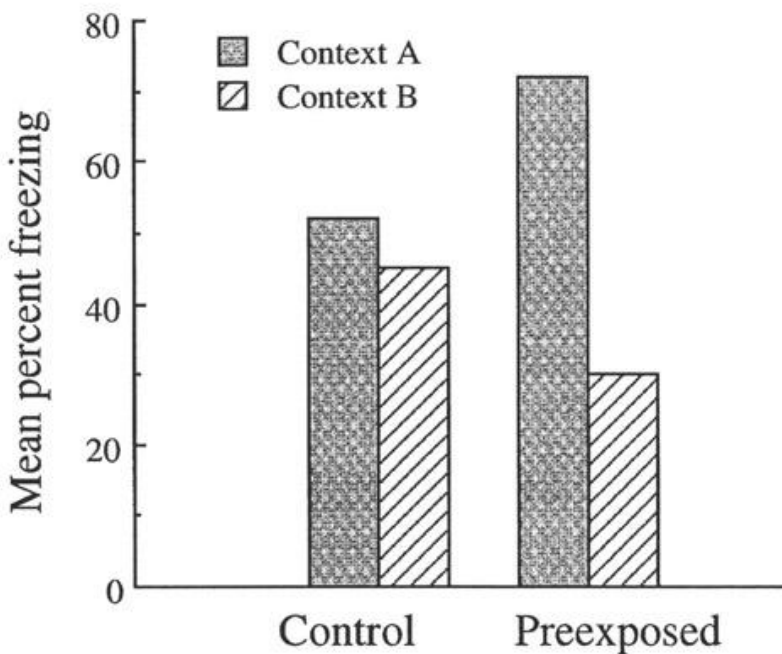
FIG. 9.3. Mean percentage of observations scored as freezing in a context previously paired with shock (Context A) and a different test context (B), for control rats given no preexposure to A and for rats given four 2-min preexposure trials with A (preexposed). From Kiernan and Westbrook (1993, Experiment 3).

that, whatever else happens during preexposure, some perceptual learning process is brought into play that acts to increase the discriminability of A and B and outweighs the effect to be expected on the basis of the magnitude of the CR governed by A. These results are silent as to the nature of this process, but Kiernan and Westbrook (1993) suggested that the associative processes proposed as the basis of unitization may

play a role. Central to their argument is the assumption that the features most likely to be sampled during brief exposure to the context given on the conditioning trial are those that it will hold in common with other similar contexts (the c elements of Fig. 9.1). For control subjects, therefore the c elements will be strongly conditioned and the presence of these elements on test with B (or with A for that matter) will allow a fairly strong CR to be evoked. For animals given preexposure to A, the features that compose this stimulus will undergo latent inhibition to some extent, the c elements will be less strongly conditioned, and the CR evoked by B will be weaker. However, preexposure will also give the animal a chance to sample the less salient a elements and to form a–c associations (the unitization process). When tested with A, the c elements may be sampled first, but as the test proceeds, a elements will also be sampled and, by virtue of their ability to activate the conditioned c elements, they will contribute to the CR observed. This effect could be enough to outweigh those of latent inhibition. With its assumption that the initial perception of the A stimulus is likely to be dominated by c elements, this ingenious explanation has something in common with the notion of stimulus differentiation. It differs, however, in that it does not suppose that exposure to A produces some permanent change in which elements are activated, in the way that the event is perceived. All it needs to assume is that c elements are more salient than a elements and that the limited capacity of the animal's processing system means that only salient elements are sampled when exposure to the stimulus is brief.

Nonreinforced Preexposure to Stimulus B

As preexposure to A can enhance the discriminability of A and B, it will come as no surprise that preexposure to B appears to be able to produce the same effect. Experiments using the flavor-aversion technique have routinely found that an aversion conditioned to A generalizes poorly to B in rats given prior exposure to B (e.g., Bennett, Wills, Wells, & Mackintosh, 1994; Best & Batson, 1977; Burch-Vernon & Riccio, 1997; Honey & Hall, 1989b; but see also Symonds & Hall, 1995). An experiment using quite a different training procedure (imprinting techniques with domestic chicks as the subjects) has generated essentially the same result (Honey, Horn, & Bateson, 1993).

It seems likely that latent inhibition plays a major role in generating this effect. During preexposure to B, the b and c stimulus elements will undergo latent inhibition and thus conditioning to A (a stimulus composed of a and c elements) will be largely a consequence of the acquisition of strength by the novel a elements. Generalized responding to B, which will depend on the strength acquired by c elements, will therefore be weak. Support for this interpretation comes from the fact that Burch-Vernon and Riccio (1997), who found a particularly strong effect, used stimuli that were very similar (milk and chocolate milk) and thus, presumably had a high proportion of c elements. Further, Bennett et al. (1994), who explicitly manipulated the common elements of the stimuli by adding a salient extra flavor to both A and B (i.e., they preexposed to BX, conditioned with AX, and tested with BX), found a potent effect only in these conditions. In other circumstances (e.g., when animals were preexposed to BY,

i.e., to a compound made up of B and some other salient flavor), generalization from AX to BX was profound. Finally, a

feature of the experiment by Symonds and Hall (1995), which found no effect of preexposure to B on generalization, was that very extensive conditioning was given with Stimulus A—such training might well have been enough to overcome the latent inhibition engendered during the preexposure phase.

There is one experiment, however, for which an interpretation in terms of latent inhibition seems not to be viable. Using auditory stimuli as A and B (a tone and white noise, counterbalanced), Honey (1990) investigated the effects of giving preexposure to A (48 trials), to B (48 trials), to both (48 trials with each), or to neither of these stimuli on the generalization to B of an appetitive response conditioned to A. The results of the test session with B are presented in Fig. 9.4. They show, first, that animals given preexposure to A generalize less than those given no preexposure, a result already mentioned and one consistent with the supposition that this preexposure endows the c elements, on which generalization will depend, with latent inhibition. Strikingly, however, the subjects given preexposure to B showed even less test responding than those given preexposure to A in spite of having received approximately equivalent exposure to the c elements. Those animals given preexposure to both stimuli, and who therefore had exposure to the c elements twice as often as animals in the other preexposed groups, showed the highest level of test performance. Considerations of latent inhibition require that this group should show the lowest level of response of all. Some process other than, or in addition to, latent inhibition must be at work in this experiment.

In explaining his findings, Honey (1990) turned to a suggestion, originally made by Best and Batson (1977), that the novelty (or familiarity) of a stimulus might be a feature that can acquire associative strength and thus mediate generalization. When the CS and the test stimulus have the same degree of novelty or familiarity, generalization will occur readily. Thus test responding will be vigorous both in the control group (for which both stimuli are novel) and in the group exposed to both A and B (for which both will be familiar). Generalization will be less in those groups for whom the stimuli do not share a common feature of this sort—that is, in the group preexposed to B (trained with a novel CS but given a familiar test stimulus) and in the group preexposed to A (who received a familiar CS and a novel test stimulus). This is an intriguing notion that might have general relevance in the explanation of perceptual learning effects (see Hall, 1991). It should be acknowledged, however, that other interpretations of Honey's results are available. A feature of Honey's procedure was that the trial durations during preexposure were different for the two stimuli, that for B being longer than that for A. It follows that the c elements had more opportunity to acquire latent inhibition in B-preexposed animals, and this may be

enough to explain their low level of test responding. It remains the case that the group given preexposure to both stimuli must have suffered the most latent inhibition of all, but here another factor may have come into play. These subjects received pretraining in which A and B occurred together in the same session, separated by only a fairly brief intertrial interval. This experience could have allowed the development of excitatory association between the stimuli and, if so, the high level of responding shown to B on test would be explicable in terms of the familiar associative

principle of sensory preconditioning. Until this matter is resolved, it would be prudent to withhold judgment on the role played by novelty and familiarity in generalization.
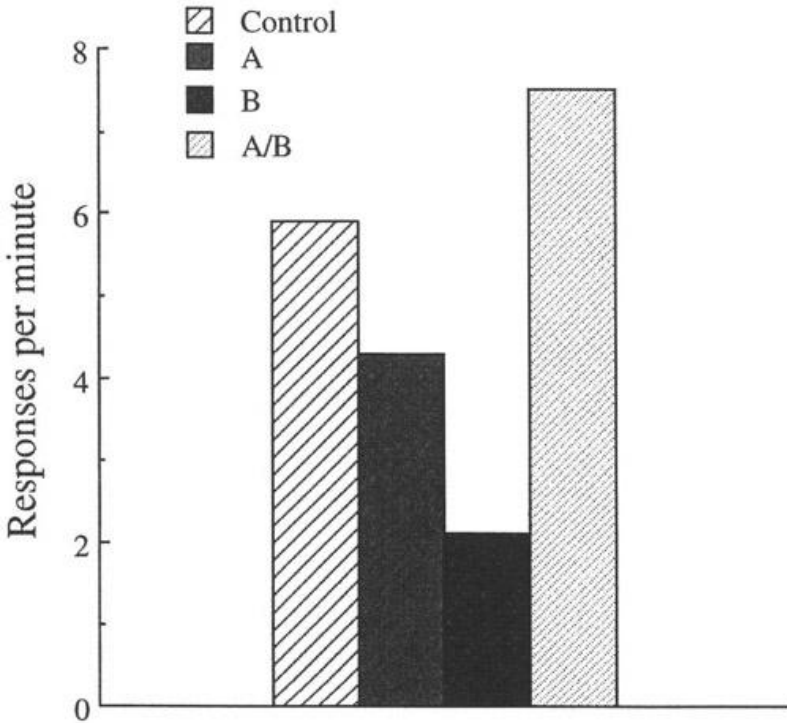

FIG. 9.4. Group mean response rates for a generalization test with Stimulus B for rats previously given food-reinforced conditioning with A. Before conditioning, different groups had received exposure to A, to B, to both stimuli (A/B), or to neither (control). After Honey (1990).

Pretraining with Both Stimuli

Differential Pretraining

Discrimination training in which the animal experiences reinforcement in association with A (A+) but not with B (B−) will establish differential responding so that the animal performs the CR to A and not to B. Standard associative theory (e.g., Rescorla & Wagner, 1972) explains this by adopting a mechanism that ensures that excitatory associative strength accrues to the a elements, inhibitory strength to the b elements, and that the c elements, which do not reliably predict an outcome, become neutralized. There is no need to suppose what has sometimes been proposed, that such training also enhances the discriminability of the stimuli. It may do so, but the formation of a discrimination in itself is not enough to prove the point. Relevant evidence on this matter comes from experiments in which the subjects are required to learn some new discrimination task involving the same stimuli. If this second task is chosen with care it is possible to ensure that direct transfer based on the responses acquired during training on the first does not contribute to the discriminative performance required in the second. In these circumstances, positive transfer has been taken to indicate that the first stage of training has led to an increase in the discriminability of the stimuli, a phenomenon referred to as the acquired distinctiveness of cues.

A Demonstration of the Effect

In a recent study, conducted in collaboration with Ward-Robinson (Ward-Robinson & Hall, 1999), I attempted

to demonstrate this phenomenon. The design of the experiment, based in part on one reported by Honey and Hall (1989a), is summarized in Table 9.1. In Phase 1, rats received training with three auditory stimuli. For one group, two stimuli (A and C) signaled the delivery of a sucrose pellet and the third (B) was not reinforced. For a second group, B was reinforced and A and C were not. After the animals had learned their Phase 1 discriminations, all received a second phase of training in which Stimulus A was paired with a new reinforcer, an electric shock. Generalization of the conditioned fear established by this training was assessed in a test of the ability of B and of C to suppress a baseline instrumental response supported by the delivery of a standard food pellet reinforcer.

The results of the generalization test are shown in Fig. 9.5. In neither group was suppression very profound, and what suppression there was tended to diminish over the course of the three test trials given with

TABLE 9.1 Design of Experiment by Ward-Robinson and Hall (1999)

Group	Phase 1	Phase 2	Generalization Test	Mediated Conditioning Test
	A → +			
A+/B−/C+	B−			
	C → +			
		A → shock	B vs. C	Lever → +
	A−			
A−/B+/C−	B → +			
	C−			

Note. A, B, and C refer to auditory stimuli that either signaled delivery of a sucrose pellet, → +, or were nonreinforced, −. Stimulus A was paired with a shock reinforcer during Phase 2. The effect of this training on the rat's willingness to earn sucrose pellets by lever pressing was assessed during the mediated conditioning test. The generalization test examined the ability of Stimuli B and C to suppress a different instrumental response.

each stimulus. In both groups, however, Stimulus C evoked more suppression than Stimulus B. The effect was more marked in Group A+/B−/C+ than in Group A−/B+/C−, but statistical analysis confirmed that the difference was reliable in both. This result may be summarized as showing that generalization occurs more readily between stimuli that have shared a common training history in Phase 1 (A and C, for both groups) than between stimuli that have been treated differently (A and B). The particular design used here allows us to avoid some of the problems that have complicated previous attempts to demonstrate such an effect (see Hall, 1991). First, all subjects received discrimination training in Phase 1. In some previous experiments comparison has been made between separate groups, one given discrimination training and one not, leaving open the possibility that any effect obtained might be a consequence of the general effects

of discrimination training rather than one based on changes in the effectiveness of specific cues. Next, in experiments using a between-groups design, it is possible that differences on test arise, not because of differences in generalization between A and the test stimulus, but because of differences in the ease with which A acquires associative strength in the second phase of training. The within-subjects comparisons allowed by the present design (between
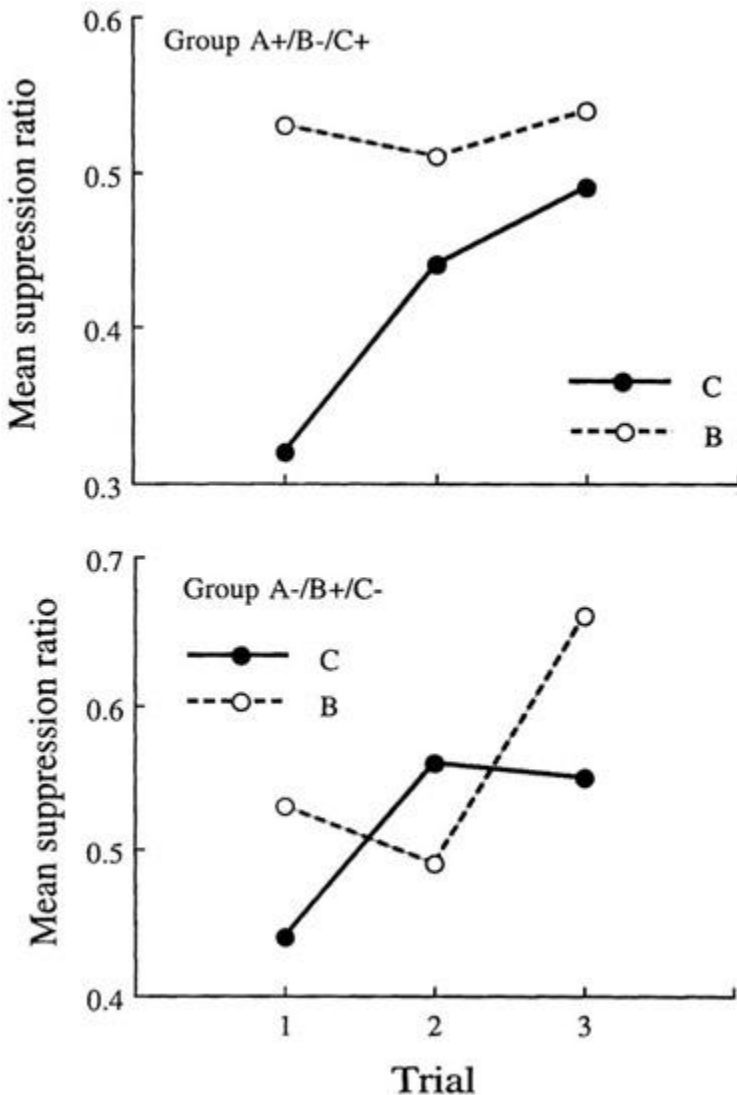
FIG. 9.5. Group mean suppression scores for each trial of the generalization test in the experiment by Ward-Robinson and Hall (1999). For both groups, Stimulus C had received the

same Phase 1 treatment as Stimulus A and Stimulus B had received a different treatment (see Table 9.1).

B and C for each group) rule out this possibility. Finally, the pattern of results shown in Fig. 9.5 cannot be the product of the transfer of CRs acquired in the first phase of training. It might be thought, for instance, that the enhanced suppression in the presence of C in Group A+/B−/C+ is simply a consequence of the interfering effects of the food-reinforced CR carried over from Phase 1 training. If this were so, however, Group A−/B+/C− should show more marked suppression to B than to C, the opposite of the result obtained.

Acquired Equivalence and Representation-Mediated Conditioning

Although this experimental design allows us to say that there is less generalization between A and B (stimuli that have undergone differential training in Phase 1) than between A and C, it does not allow us to conclude that this effect is the consequence of the acquisition of distinctiveness by A and B—it could reflect a reduction in the animal's ability to discriminate A from C (the stimuli that were trained in the same way in Phase 1). The notion that a common training history might result in the acquired equivalence of cues has a long history and a possible associative basis for the phenomenon was proposed by Hull (1939). The essence of Hull's proposal (expressed, of course, in rather different terminology) was that the associate of a stimulus might be capable of acquiring associative strength and could thus mediate generalization to some other different event that shared the same associate. It is as if an extra c element has

been added to both the stimuli. Applied to the results shown in Fig. 9.5 (see also Honey & Hall, 1989a) the argument runs as follows. In Phase 1 of training, Stimulus A (for Group A+/B−/C+) forms an excitatory association with the sucrose reinforcer. In Phase 2, therefore, the sucrose representation will be associatively activated in the presence of the shock reinforcer, allowing the possibility that a sucrose-shock association will be formed (see Hall, 1996). On the generalization test, Stimulus C, but not Stimulus B, will be able to activate the sucrose representation and thus contact the shock reinforcer by way of the chain C−sucrose−shock. Some suppression can therefore be expected in the presence of C. A similar analysis can be applied to Group A−/B+/C−where the mediating event (the associate shared by A and C) will be the state (of frustration, say) engendered by the fact that neither stimulus was paired with sucrose in Phase 1.

Central to this interpretation is the assumption that the associatively activated representation of an event can serve as a CS, forming excitatory associations with a reinforcer. Hall (1996) reviewed the evidence for this assumption. Perhaps the strongest comes from the work of Holland (e.g., 1981, 1983, 1990), who showed that pairing the presentation of a tone with a nausea-inducing injection will create an aversion to a distinctively flavored food pellet that has previously been signaled by the tone. This result, he argued, reflected the formation of an association between the associatively activated representation of the flavor and the state of nausea. My analysis of the acquired equivalence effect assumes exactly this process, but with shock rather than nausea serving as the reinforcer. Unfortunately, for present purposes, Holland (1981) extended his work to investigate the effect of a shock reinforcer and found no evidence of

representation-mediated conditioning in these circumstances. That is, rats that had experienced tone–pellet pairings followed by tone–shock pairings showed no evidence of an aversion to the food pellets in a final consumption test.

Although Holland's (1981) results were not encouraging, we (Ward-Robinson & Hall, 1999) thought it possible that his failure to find an effect might be a consequence of the insensitivity of the test procedure that was used. Holland (1981) used a simple consumption test, but there is some evidence to suggest (Jackson & Delprato, 1974) that a test in which the animals must perform an instrumental response to earn the pellet may give a more sensitive measure. Accordingly, we extended the experiment outlined in Table 9.1 to include a further test (the mediated conditioning test) in which a lever was made available for the first time, responding on which produced the sucrose pellets that had been used in Phase 1 of training. (For half the animals this test followed the generalization test; for the remainder the order of the tests was reversed.) For animals in Group A+/B−/C+, pairings of the representation of the sucrose pellet with shock will have occurred during Phase 2 training. This might be revealed in their showing an unwillingness to lever press for these pellets. The performance of this group can be conveniently assessed by comparison with that shown by Group A−/B+/C−, for whom no such pairings will have occurred. Any effect produced by this test will be a consequence of training procedures that are known to result in an acquired equivalence effect.

In the mediated conditioning test, the rats were permitted to perform 11 lever presses, each of which caused the delivery of a single sucrose pellet. The first response started a timer so

that the latency of the subsequent 10 responses (those performed after a sucrose pellet had been encountered) could be recorded. Group mean latencies are presented in Fig. 9.6. As would be expected of rats learning a new instrumental response, latencies tended to decline over the course of the test. This decline occurred steadily in Group A−/B+/C−. Strikingly, however, Group A+/B−/C+ showed very long latencies early in the test. (Statistical analysis showed that the groups differed reliably in their latencies for Responses 2 and 3.) This difference indicates that the sucrose pellet

was a less effective reinforcer for the latter group than for the former, the outcome that would be expected if the pairing of A with shock in Phase 2 endowed A's associate (sucrose for Group A+/B−/C+) with some degree of aversiveness. Although the simple cooccurrence of two phenomena cannot prove the existence of a causal relation between them, the demonstration of acquired equivalence and mediated conditioning in the same experiment adds support to the argument that the former is a consequence of the latter.

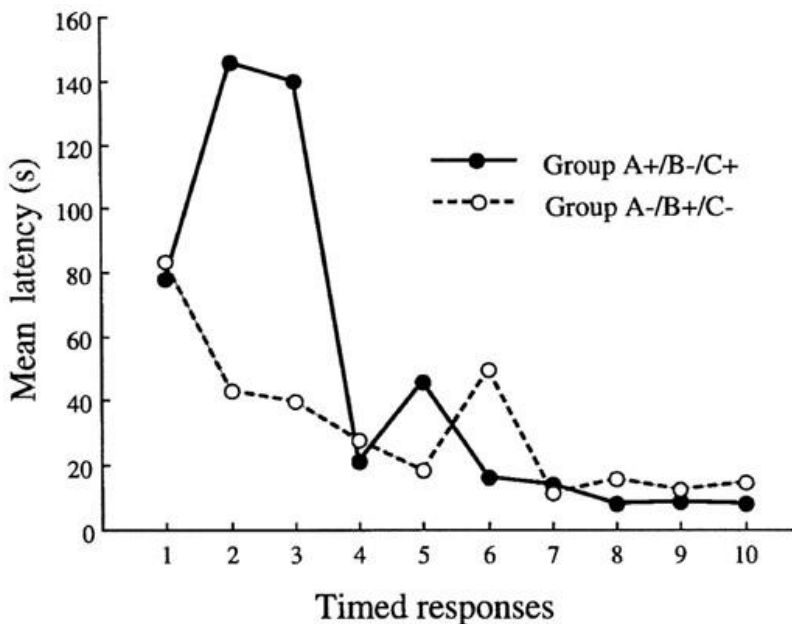## Acquired Distinctiveness and Attentional Factors

FIG. 9.6. Group mean latency data from the mediated conditioning test of the experiment by Ward-Robinson and Hall (1999). Scores represent the interval between successive responses after the first response.

The conclusion merited by the evidence discussed so far is that results of the sort depicted in Fig. 9.5 can be explained perfectly well in terms of acquired equivalence between Stimuli A and C. This does not prove, however, that the discrimination training given to A and B was without effect—equivalence and distinctiveness could be acquired concurrently. To prove the reality of acquired distinctiveness,

however, it is necessary to compare the performance of subjects given initial discrimination
training with that of control subjects who have not had the opportunity to build up an acquired equivalence between the stimuli but who are matched to the discrimination-trained subjects in other relevant respects (e.g., in their exposure to the stimuli and their general experience of the training situation). As Hall (1991) pointed out, a control condition that meets these criteria has been very hard to find. There is a recent series of experiments by Delamater (1998), however, that makes some progress in this direction.

Delamater's (1998) basic procedure involved the use of two sets of stimuli, an auditory pair (tone and white noise; A1 and A2) and a visual pair (steady and flashing light; VI and V2), and two reinforcers, sucrose and standard food pellets (S and F). Animals can thus be given differential pretraining in which both stimuli of a given modality are followed by (different) reinforcers (e.g., A1→F; A2→S) and transfer to a new task can easily be arranged by omitting one of the reinforcers (i.e., A1→F; A2→0). The dependent variable is the rate at which this second discrimination is formed. Control subjects receive the same reinforcer in association with the two stimuli in the first phase of training (A1→F; A2→F). The use of the second set of stimuli makes it possible to equate the two groups in terms of their experience of the reinforcers. With these stimuli the control subjects experience VI→S and V2→S and the experimental subjects V1→F and V2→S. Using these procedures, Delamater demonstrated that the transfer discrimination is acquired more readily in subjects given differential training in the first phase than in control subjects.

This basic result can be accommodated, as Delamater (1998) acknowledged, by an interpretation in terms of mediated conditioning and acquired equivalence. When control subjects experience a nonreinforced (A2→0) trial in the test discrimination, the A2 cue, as a result of the first stage of training, will be able to activate the F representation. Thus the possibility arises that associative activation of the representation of food will become a signal for its omission. Such learning can only detract from performance on A1 trials because on these trials the event that has previously signaled food continues to do so. For experimental subjects, on the other hand, it will be the representation of S that becomes associated with nonreinforcement. Performance to A1 (supported by a different reinforcer, F) will accordingly suffer less. In a further experiment, however, Delamater modified his basic design to produce a result that cannot be explained in this way.

The design of the critical experiment is outlined in Table 9.2. As before, animals in the experimental condition (the distinctiveness group of the table) were trained initially with one auditory and one visual cue followed by S, the other cues being followed by F. Animals in the control (equivalence) group experienced one reinforcer type along with the auditory cues and the other with the visual cues. It should be noted that the group labels refer to the condition that applies within a modality; between modalities the position is reversed. We may assume, however, that when it comes to the test, the animal's chief task is to discriminate one auditory cue from the other and one visual cue from the other. The form of the test is shown on the right of Table 9.2. Its novel feature is that the subjects were required to learn two discriminations concurrently: A1 continued to be reinforced

as before but the reinforcer for A2 was omitted; V2 continued to be reinforced as before but the reinforcer for VI was omitted. Performance on this test (pooled over both discriminations) and on a subsequent reversal of the discriminations is shown in Fig. 9.7. It is evident that performance was superior in the distinctiveness group.

TABLE 9.2 Design of Experiment by Delamater (1998)

Group	Training	Test
Distinctiveness (within modality)	A1 →F / A2 → S	
	V1 → F / V2 → S	
		A1 → F / A2 → 0
		V1 → 0 / V2 → S
Equivalence (within modality)	A1 → F / A2 → F	
	V1 → S / V2 → S	

Note. A1 and A2 = auditory cues (tone and noise); V1 and V2 = visual cues (steady and flashing light); F = food; S = sucrose pellets. Only specimen groups are portrayed (the full design was counterbalanced). After 16 sessions of training on the test, the animals were trained on the reversal of this discrimination.

It is difficult to explain the results of Fig. 9.7 in terms of acquired equivalence produced by representation-mediated conditioning. As before, an association formed on A2→0 trials, for example, between the expectancy of F and its omission will tend to detract from performance in the equivalence group on A1 trials on which the stimulus continues to lead to F. However, something of the same sort will also be true of the distinctiveness group. For these

animals the A2→0 trials might result in the formation of an association between the expectancy of sucrose and reinforcer omission. This may not interfere with the food-reinforced A1 trials, but it can be expected to cause a problem on the other discrimination in which V2 trials continue to lead to sucrose. Thus, by requiring the animals to learn two discriminations concurrently, the postulated interference from acquired equivalence is equated in the two groups. The advantage shown by the distinctiveness group must be the consequence of some other acquired distinctiveness process.
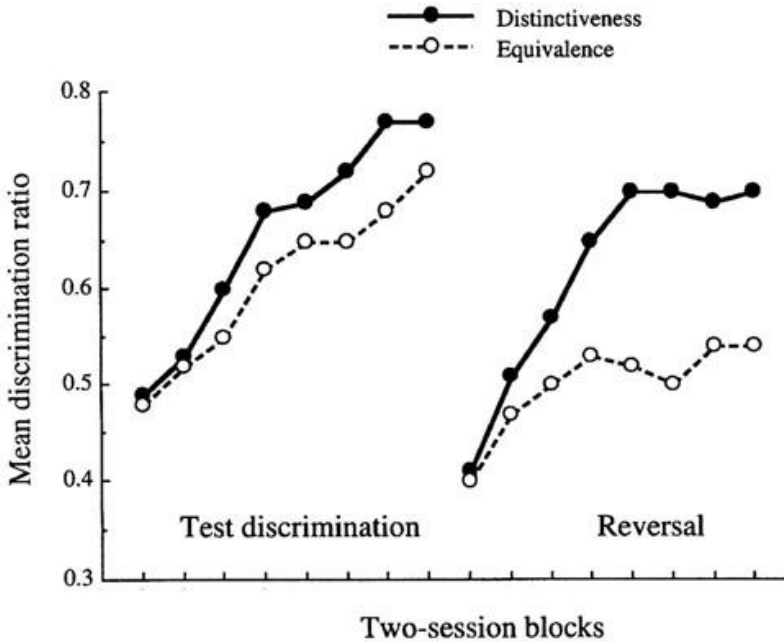

FIG. 9.7. Mean discrimination ratios (rate on positive trials / rate on all trials) for the test discrimination and its reversal in the experiment by Delamater (1998, Experiment 2). One

group had previously received within-modality distinctiveness training; the other group had received within-modality equivalence training (see Table 9.2).

Delamater's (1998) suggestion was that differential pretraining enhances the tendency of the animal to attend to distinctive features of the stimuli. Standard associative theory can readily be extended to accommodate such a process. We have already noted that the associative account of discrimination learning (A+/B−) assumes that the a elements of the stimuli become associated with one outcome, the b elements become associated with the other, and that the c elements become neutralized. In Delamater's experiments, the outcomes are F and S rather than reinforcement and nonreinforcement, but the same principle applies. That the associations formed in the distinctiveness condition involve just a and b elements and not c elements does not, in itself, predict that a subsequent discrimination involving A and B will be advantaged. However, if we add the assumption that, in addition to the mechanism responsible for association formation, there also exists an attentional learning mechanism that selectively boosts the associability of predictive stimuli, then the result follows. The formal theory of attention in animal conditioning proposed by Mackintosh (1975) has just this property (but see also Hall, 1991; Pearce & Hall, 1980).

Before accepting these results as proof of the operation of an attentional learning mechanism, a possible alternative interpretation should be considered. Although associative learning principles are more comfortable with the notion of equivalence than that of distinctiveness, it is not beyond their scope to supply an explanation of the latter. Hall (1991) discussed a number of possibilities, one of which may be

applicable here. Discrimination training is assumed to establish associations between cues and their (different) consequences (e.g., A1→F and A2→S in the experiments just described). This means that on subsequent presentation, each cue will elicit activity in the representation of its associate. It has long been accepted that the simultaneous presentation of another cue may modify the way in which a target cue is perceived (the principle of generalization decrement). Hall suggested that such effects might also operate when the added cue is not itself physically present, but is the associatively activated representation of an event. An untrained A stimulus may be perceived in one way, one that evokes the representation of F in a different way, and one that evokes the representation of S in a different way again. Establishing A1–F and A2–S associations could mean that the perception of A1 is changed in one way and the perception of A2 is changed in different way. These effects will operate on all features of the stimuli, including those that are common to both. Thus the number of c elements may be reduced, and discrimination between the stimuli will be enhanced, resulting in the acquired distinctiveness effect. This account is frankly speculative and there is little independent evidence to support it. It is presented here simply to make clear that we cannot yet accept, as undisputed truth, the idea that discrimination training increases the attention paid to distinctive features of the stimuli.

Nonreinforced and Nondifferential Pretraining

To accept that acquired distinctiveness may occur because of an increase in the attention paid to features that distinguish between stimuli and a reduction in attention to

nondistinguishing features is to accept an important aspect of Gibson's (1969) notion of stimulus differentiation.

However, the two interpretations are not identical. In the attentional account just described, changes in attention are taken to be a consequence of associative changes—in Mackintosh's (1975) theory, a stimulus (or stimulus feature) has its associability boosted because, as a good predictor of reinforcement, it gains associative strength more readily than other stimuli. Differential reinforcement is necessary to produce attentional learning. Gibson, by contrast, denied this necessity. Discrimination training may be helpful because it maintains attention generally (the animal stays awake during pretraining) and thus ensures that the stimuli are properly experienced; but the differentiation process does not depend on differential reinforcement—mere exposure to the stimuli will suffice. To investigate this suggestion, it is necessary to look at experimental procedures in which animals are required to learn an A+/B− discrimination after preexposure in which neither stimulus is reinforced or, if reinforcement is present in pretraining, it is given equally in association with both stimuli.

Some Examples of the Effect

The classic study of exposure learning is that described by Gibson and Walk (1956) in which young rats were given prolonged preexposure in the home cage to two geometrical objects that later were presented as the stimuli in a simultaneous discrimination task conducted in a conventional choice apparatus. Preexposure was found to facilitate discrimination learning (see also Hall, 1979, 1980). This procedure has not been used much recently, but related

experiments using a range of different procedures have been conducted over the last decade and they have largely confirmed the reliability of this perceptual learning effect.

An example of the effect in maze learning comes from an experiment by Trobalon, Sansa, Chamizo, and Mackintosh (1991; see also Chamizo & Mackintosh, 1989). Rats in the preexposed condition were allowed to explore, on separate trials, the two maze arms (arms differing in the nature of the floor covering, rubber or sandpaper) that subsequently they would be required to discriminate between. Control subjects were given equivalent exposure to the apparatus, but encountered an unrelated stimulus (a maze arm covered in plastic) on each trial. In the test phase, access to two arms was possible for the first time, with food available at the end of one of them. This rubber–sandpaper discrimination was learned more rapidly by the subjects that had been preexposed to these stimuli.

A further example using very different procedures is found in a study reported by Honey and Bateson (1996, Experiment 1). This experiment made use of imprinting procedures with domestic chicks as the subjects.

In the first phase of training, experimental subjects were given, on separate trials, exposure to two objects, A and B. This training was effective in establishing imprinting (i.e., the tendency to emit filial responses) to both objects. Control subjects were exposed to the apparatus, but A and B were not presented. On the following day, all subjects received training in which they were placed in a cool cabinet with Object A displayed at one end and Object B at the other. Approach to one of the objects was rewarded by the delivery of a stream of

warm air. Experimental subjects were found to learn this discrimination more readily than the controls.

For the most part, however, modern studies of the perceptual learning effect have made use of the flavor-aversion learning procedure (e.g., Honey & Hall, 1989b; Mackintosh, Kaye, & Bennett, 1991; Symonds & Hall, 1995). An experiment by Symonds and Hall (1995, Experiment 1) serves as an example. All subjects in this study received the same test procedure in which an aversion was established to Flavor A followed by a generalization test to Flavor B. Over the preceding 8 days, subjects in the experimental condition (Group A/B) had experienced four trials with each of these flavors presented on alternate days. Control subjects (Group W) received only water on these pretraining trials. The experiment also included two further groups: Group B, given four presentations of Flavor B during pretraining, and Group A given four presentations of A. The results of the test are shown in Fig. 9.8. Generalization was profound in Group W, was slightly less in Group A and Group B, but was dramatically attenuated in Group A−B. It appears that the A/B discrimination is facilitated in animals given nonreinforced preexposure to both stimuli.

Before turning to a discussion of explanations for this effect, the contrast between these results and those reported by Honey (1990; see Fig. 9.4) requires comment. Honey found a significant attenuation of generalization in the equivalents of Groups A and B. The failure to find this effect here may simply be a consequence of the fact, already mentioned, that the experiment by Symonds and Hall (1995) used a very potent conditioning regime for the A+ stage (three trials with a high concentration of lithium as the reinforcer), a procedure

that established a strong aversion to A in all groups. This regime could have been enough to obscure differences produced by latent inhibition effects that were operating in Honey's (1990) experiment. Perhaps more significant is the fact that Honey found enhanced generalization in his equivalent of Group A/B. In my earlier discussion of this result, I speculated that it might be the consequence of excitatory associations formed between A and B. The fact that the reverse result is obtained in a procedure in which such associations are unlikely to form (for Group A/B in this experiment there was an interval of 24 hr between successive presentations of A and B

during preexposure) lends support to this speculation. However this may be, we will take as the central finding in need of explanation the observation that prior exposure to A and B usually enhances discrimination, or reduces generalization, between these stimuli.
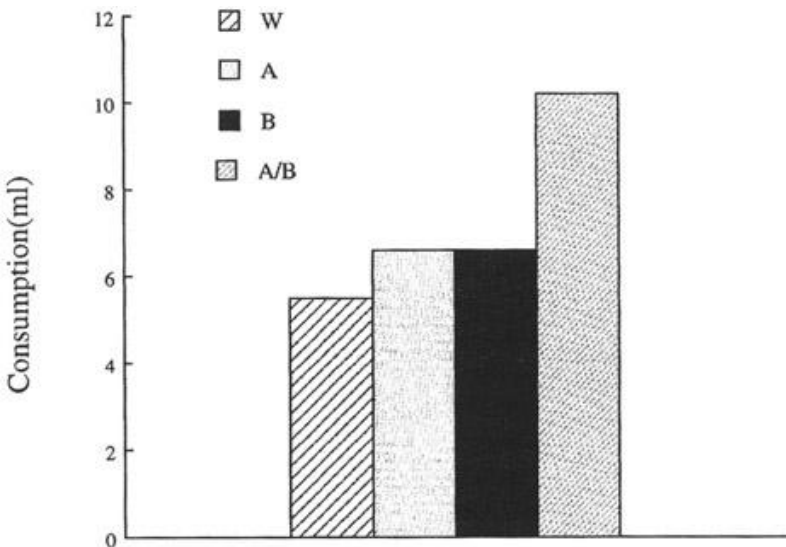
FIG. 9.8. Group mean scores for consumption of Flavor B after conditioning with Flavor A in the experiment by Symonds and Hall (1995, Experiment 1). Before conditioning, different groups had received exposure to A, to B, to both stimuli (A/B), or to neither (W).

The Role of Latent Inhibition

That preexposure to both stimuli should be especially effective in producing the perceptual learning effect is anticipated by Gibson's (1969) concept of differentiation. Although the mechanism is not specified, it seems clear that the process of differentiation (which involves an increased sensitivity to a and b elements and a reduction in the attention paid to the c elements) will be fostered by giving the animal a chance to compare the stimuli and thus detect which elements are common and which are unique (see Gibson, 1969). There is, however, an alternative explanation available that has no need to assume the existence of a special process of stimulus comparison. As we have already acknowledged, preexposure to one of the stimuli (either A or B) will result in latent inhibition of c stimulus elements and thus can be expected to attenuate

generalization to some extent. However, as McLaren et al. (1989) pointed out, preexposure to both A and B will mean that the c elements receive twice as much preexposure (they will be present on both A and B trials); the latent inhibition suffered by the c elements will be particularly profound in this case, and generalization will be even less, producing the pattern of results seen in Fig. 9.8.

Symonds and Hall (1995, Experiment 2) conducted an experiment using the flavor-aversion procedure that was designed to allow a choice between these alternative interpretations. There were three groups of rats differing in the pretraining they received. One group received the standard preexposure treatment—trials with Flavors A and B presented in alternation (Group A/B–I, where I denotes intermixed presentations of A and B). Control subjects (Group W) received only unflavored water in this stage. The third group (A/B–B, for Blocked) received the same amount of preexposure to A and B as did Group A/B–I but the different trial types were arranged in separate blocks. That is, these subjects received a block of A trials followed by a block of B trials, or vice versa. All subjects then received conditioning with A as the CS, followed by a generalization test with B. In both preexposed groups the c elements will have suffered latent inhibition during preexposure, and, to the extent to which this factor determines generalization, the aversion to B should be less in these groups than in Group W. However, as the total amount of exposure to the stimuli is equated in the B and I conditions, the extent to which latent inhibition accrues to the c elements in Groups A/B–I and A/B–B should be the same; on the basis of latent inhibition, therefore, there are no grounds to expect a difference between the two preexposed groups.

The results of the test phase of this experiment are presented in Fig. 9.9. Generalization was profound in Group W but was markedly attenuated in the group given intermixed preexposure; that is, the basic perceptual learning effect was reproduced here. This result is not a consequence of latent inhibition. Group A/B–B, which had the same amount of

exposure to the stimuli as Group A/B–I, showed almost as much generalization as the control group.[1]

Simply giving the c stimulus elements the opportunity to undergo latent inhibition is not enough to reduce generalization—it is critical that the subjects also experience the other elements of the stimuli (the a and b
elements) in an intermixed schedule (see also Symonds & Hall, 1997). Results from experiments using the imprinting procedure with chicks confirm this conclusion. Honey, Bateson, and Horn (1994; see also Honey & Bateson, 1996) compared chicks given blocked exposure (100 presentations of Object A in one session and 100 of Object B in a separate session) with chicks given intermixed exposure (50 presentations of each stimulus in each session). When the objects used as A and B were similar, the subjects given intermixed preexposure were found to learn a subsequent discrimination between A and B more rapidly than those given blocked preexposure.
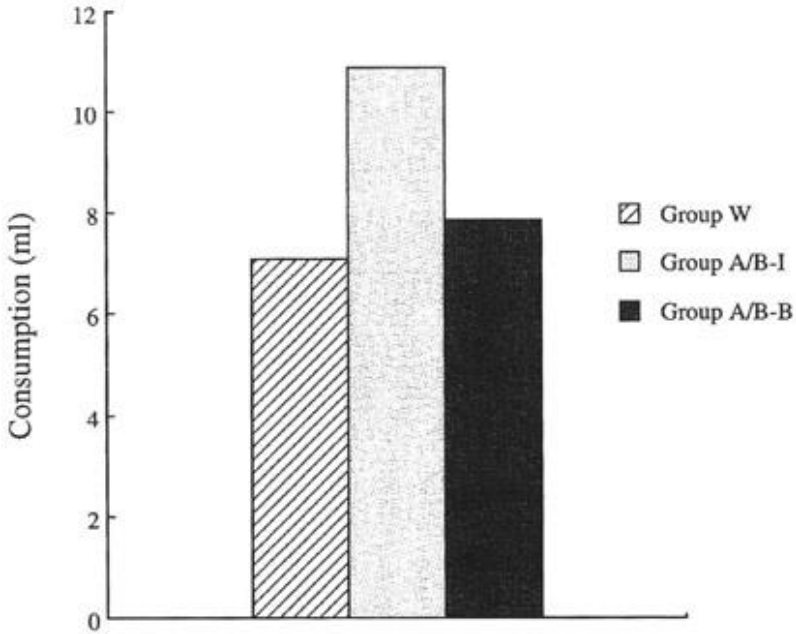
FIG. 9.9. Group mean scores for consumption of Flavor B after conditioning with Flavor A in the experiment by Symonds and Hall (1995, Experiment 2). Before conditioning, different groups had received exposure to A and B presented in an intermixed fashion (A/B–l), to A and B presented on separate blocks of trials (A/B—B), or to only unflavored water (W).

Symonds and Hall (1995) concluded that the superior discrimination evident in the intermixed condition was consistent with the suggestion that the perceptual learning effect depends on the operation of
a process of stimulus comparison. Although we were unable to specify the mechanism by which comparison might operate, we felt reasonably comfortable with the assumption

that, whatever the mechanism might be, comparison was more likely in the intermixed case than in the blocked case.

The Role of Associations Within and Between Stimuli

In their analysis of perceptual learning, McLaren et al. (1989) pointed out that giving nonreinforced preexposure does not preclude the operation of associative processes. Although they do not become associated with an orthodox reinforcer, stimuli given such preexposure are likely to form associations with other events, such as the context in which they occur and, if they are presented close enough together in space and time, with each other. Accepting that the event or object referred to as "a stimulus" should be construed as consisting of a set of elements, each of which can enter into associations, opens up a range of other possibilities. In my discussion of unitization I have already noted that mere exposure to a stimulus should allow excitatory associations to form among its constituent elements (i.e., within-stimulus associations will develop). Put simply, exposure to A should allow a–c links to form; exposure to B should allow b–c links to form. Furthermore, for animals exposed to both A and B, the formation of these within-stimulus links can be expected to contribute to the formation of between-stimulus associations, even when A and B are presented on quite separate occasions. In this case, however, the associations will be inhibitory. Once presentations of A have established the excitatory a–c association, presentation of B, a stimulus containing c elements, will be able to activate the representation of a. According to standard theory (e.g., Wagner, 1981; Wagner & Rescorla, 1972) this combination of events will result in

inhibition forming between the stimulus that is present and the representation that is activated only associatively. If the excitatory a–c association is maintained by continued presentation of A, it can be predicted that inhibitory power will accrue chiefly to the unique, b, elements of Stimulus B. Similarly, on A trials, a will acquire an inhibitory connection with b. In short, mutually inhibitory links will be formed between the unique elements of each compound as a occurs only on trials when b does not, and vice versa.

McLaren et al. (1989) argued that these various associations may play an important role in determining generalization between A and B. For animals given no preexposure to the stimuli, an excitatory a–c link will form for the first time during reinforced trials with A, at the same time as associations are being formed between these stimulus elements and the reinforcer. Generalized responding to B will presumably depend
largely on the associative strength acquired by c elements, but the a–c link will also make a contribution—the reinforcer representation will be activated not only directly by c but also by way of the associative chain, c-fl-reinforcer. Preexposure to A and B, at least when these stimuli are presented on an intermixed schedule, will eliminate this extra source of generalization. Such preexposure will establish mutually inhibitory connections between a and b with the result that the c elements of Stimulus B will be unable to activate the a representation on the test. In the absence of the contribution from the associatively activated a elements, generalization will be less. Thus the basic perceptual learning effect can be accommodated.

This analysis also provides an explanation for the differing effects of intermixed and blocked preexposure schedules. An inhibitory link between a and b will be formed on an A (i.e., an ac) preexposure trial only when the excitatory c–b link already has some strength; similarly B (be) trials will be effective in producing inhibition only when the excitatory c–a link already exists. The alternation of A and B trials of the intermixed procedure is ideal for ensuring that the relevant connections have strength on each trial. With the blocked procedure, on the other hand, there is only a single transition from one trial type to the other; excitatory associations established during the first block will extinguish during the second, and there will be little opportunity for inhibitory links to form. Accordingly, the c–a association will be able to contribute to test performance in animals given blocked preexposure, and generalization to B should be greater than that seen after intermixed preexposure.

We thus have two explanations available for the differing effects on generalization produced by blocked and intermixed preexposure schedules. One proposes that the differing opportunities for stimulus comparison afforded by the two schedules result in differing amounts of stimulus differentiation; the other explains the effect purely in associative terms. Alonso and Hall (1999) conducted the following experiment in an attempt to decide between these alternatives. The procedures used were modeled on those of Symonds and Hall (1995) but differed in that two drinking bottles were made available to the rat on each exposure trial. For rats in the blocked preexposure condition, both bottles contained the same flavored solution, Flavor A for the first block of preexposure trials and Flavor B for the second block (or vice versa). For rats in the concurrent preexposure

condition, however, the two bottles contained different flavors (A and B) throughout preexposure. A control group received access only to unflavored water at this stage. All animals then received aversion conditioning with A, followed by a generalization test with B.

The concurrent procedure of this experiment was intended to equate to the intermixed procedure of the earlier studies in allowing the animals
the opportunity to compare the stimuli—indeed, we may suppose that comparison processes are likely to be more effective with this procedure, in which the flavors will be sampled in quick succession, than in the intermixed procedure when they are presented several hours apart. On these grounds a substantial perceptual learning effect can be expected, with group concurrent showing less generalization than group blocked. The associative theory, by contrast, predicts no such effect—concurrent preexposure to A and B will preclude the possibility of inhibitory connections forming between them and, if no other factors operate, the degree of generalization should be the same in the two preexposed groups. The results of the generalization test, shown in Fig. 9.10, lend no support to the stimulus comparison theory. Both preexposed groups showed less aversion to B than did the control group
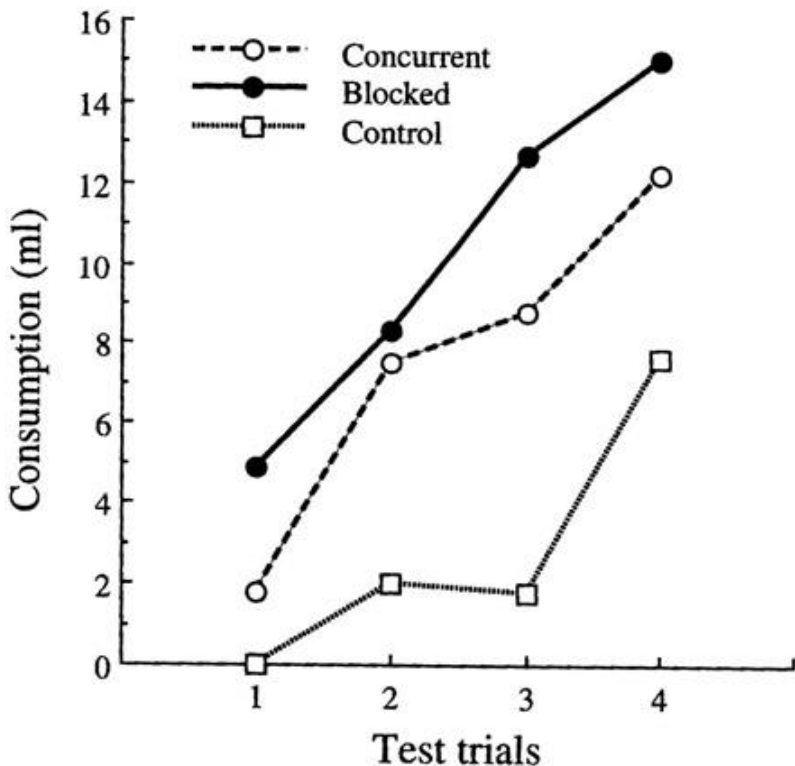
FIG. 9.10. Group mean consumption of B over four generalization test trials in the experiment by Alonso and Hall (1999). Group Concurrent had received preexposure in which Flavors A and B were made available at the same time; Group Blocked received preexposure consisting of a block of A trials and a separate block of B trials; Group Control received no preexposure to the flavors.

(as might be expected from considerations of latent inhibition), and although these two groups differed, it was not in the way predicted by the comparison theory—group

concurrent showed significantly more generalization than group blocked.

The associative theory can easily be extended to deal with the superior generalization shown by group concurrent. Not only will presenting A and B concurrently preclude the formation of inhibitory a–b links of the sort discussed earlier, it might actually allow the formation of direct excitatory associations between the two flavors—an animal that samples both drinking bottles during a preexposure trial will frequently be exposed to A–B pairings. The familiar principle of sensory preconditioning leads to the conclusion that Stimulus B will then be rendered capable of eliciting a CR conditioned to its associate, A. Alonso and Hall (1999) conducted a further experiment that produced results entirely consistent with this interpretation. Rats given the concurrent preexposure treatment initially were subjected to a second phase of preexposure (a block of trials in which A was presented alone followed by a block of trials in which B was presented alone) designed to extinguish any associations between A and B that might have formed in the first phase. Generalization in these subjects was found to be much the same as that shown by subjects in a comparable blocked-preexposure condition. Significantly, there was no indication that eliminating these associative effects allowed the effects of a stimulus comparison to show themselves. We must conclude that experiments using flavor-aversion learning procedures with rats produce no results that cannot be accommodated by a version of standard associative learning theory. For results that seem to indicate the operation of a distinct perceptual learning process it is necessary to turn to a quite different experimental paradigm—visual discrimination learning in the pigeon.

# Nondifferential Preexposure and Discrimination Learning in Pigeons

In a recent series of experiments (conducted in collaboration with Mondragon) I attempted an exploration of the role played by stimulus comparison in the discrimination learning of pigeons (Hall & Mondragon, 1999). In these experiments two pairs of stimuli were used: two shapes (call them A and B) and two colors (X and Y). Our preexposure procedure made use of the fact that it is possible to present two stimuli simultaneously on the side keys of a three-key pigeon chamber. In the first experiment to be reported here, two groups of pigeons received preexposure in this way. One group (Group C, for comparison) received 12 sessions of preexposure each consisting of 40 trials.

On 20 of these trials the two shapes (A and B) were presented, on the others, the two colors (X and Y) were presented. These birds thus had the opportunity to compare the members of each pair of similar stimuli. The other group (Group NC, for noncomparison) received the same number of preexposure trials, but the stimulus pairings were different; on some trials they saw A and Y together and on others they saw, X and B. They thus had no opportunity to make a direct comparison between the two shapes or the two colors. To ensure that the birds attended to the keys during preexposure, (nondifferential) reinforcement was given. A peck at either of the keys turned off that keylight and resulted in the delivery of grain. The other key remained lit until it too had been pecked. A response to this key again turned off the keylight, produced food reinforcement, and initiated the intertrial interval. The design of the experiment is presented schematically in Fig. 9.11.

In the test phase of the experiment (see Fig. 9.11), all birds were trained with a successive discrimination procedure, the stimuli being presented on the center key. One of the shapes (A) and one of the colors (X) continued to be associated with food reward; the other stimuli (B and Y) were nonreinforced. There were 80 trials per session in this stage, 20 with each stimulus. Positive stimuli were presented for up to 10 sec, but were turned off and reinforcement was delivered if the bird responded to them. Negative stimuli were presented for a minimum of 10 sec and were terminated only after the bird had refrained from pecking for a period of 2 sec. We assume that discrimination between the colors and shapes is easy but that there may be considerable generalization between the two colors and between the two shapes. The test task can thus be construed as involving two concurrent discriminations, A+/B− and X+/Y−. It follows that a preexposure procedure that enhances discrimination between the colors and between the shapes should be particularly effective in promoting acquisition in the test phase.

Presenting stimuli simultaneously on two keys during preexposure allows the possibility that excitatory associations will form between them (see, e.g., Zentall, Sherburne, Roper, & Kraemer, 1996). With this experimental design, however, these associations should not contribute to any difference between the groups in their test performance. Birds in Group C will form associations between A and B and between X and Y; birds in Group NC will form associations between A and Y and between X and B. In each group, therefore, associations will exist between each positive test stimulus and one of the negative stimuli. Such associations might retard acquisition of the discrimination, but they will do so in both groups. With this factor controlled for, we hoped to be able to

demonstrate that the opportunity for stimulus comparison during preexposure would facilitate subsequent discrimination learning. The results obtained (see Fig. 9.12) revealed no such effect. The groups did

not differ over the first five sessions of the test, but thereafter, Group NC pulled ahead of Group C. The difference was small but proved to be statistically reliable, p < .05 (see also Hall, 1976; Hall & Channell, 1980).
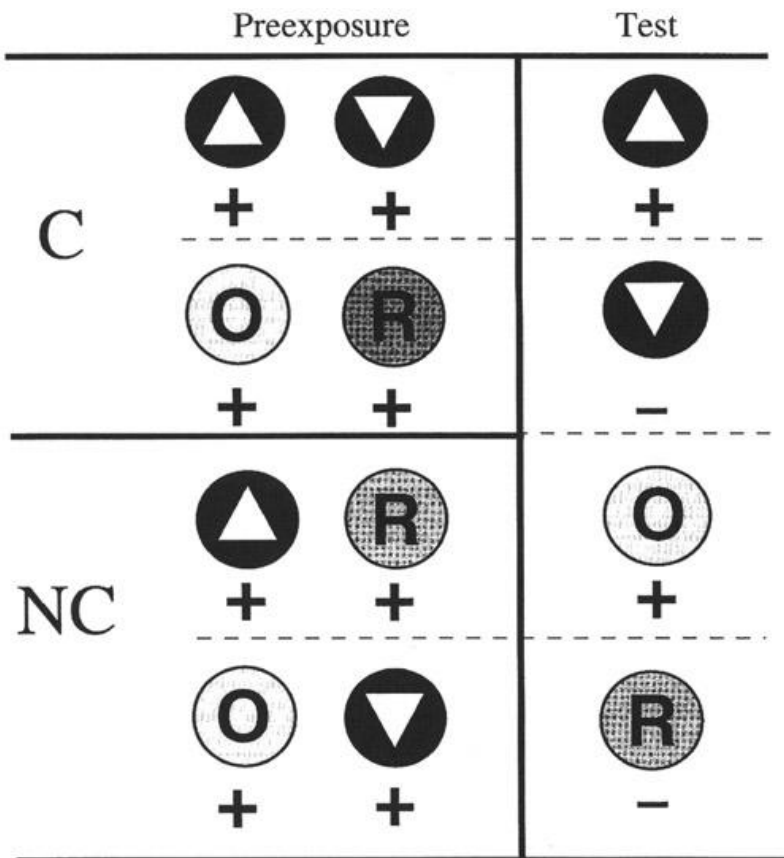
FIG. 9.11. Design of experiment on discrimination learning in the pigeon. In preexposure, all subjects were presented with two illuminated keys on each trial, Group C (for comparison) saw two shapes or two colors on each trial; Group NC (noncomparison) saw one shape and one color. Example trials are shown in the figure (the full design was counterbalanced). The test consisted of a successive discrimination with four trial types. R = red keylight; O = orange keylight; + = food reward; − = no reward.

Why should Group NC show better test performance than Group C? One possible explanation can be derived from the associative account of perceptual learning effects, described in the preceding section of this chapter. Consider the stimulus pair, A and B (similar arguments will apply to X and Y). These are taken to consist of the compounds ac and bc and, as before, it may be assumed that preexposure allows the formation of excitatory associations between a and c and between b and c. Inhibitory learning will then become possible. For Group NC, which sees A on trials when B is absent and B on trials when A is absent, a will signal the absence of b and b will signal the absence of a; mutually inhibitory associations will form between these stimulus elements. No such associations will form in Group C, which sees A and B together on the same trial. In the latter group, therefore, the excitatory a–c and b–c associations will be able to contribute to generalization between A and B. However, for Group NC the inhibitory associations between a and b will eliminate this source of generalization and discrimination learning will proceed more readily.
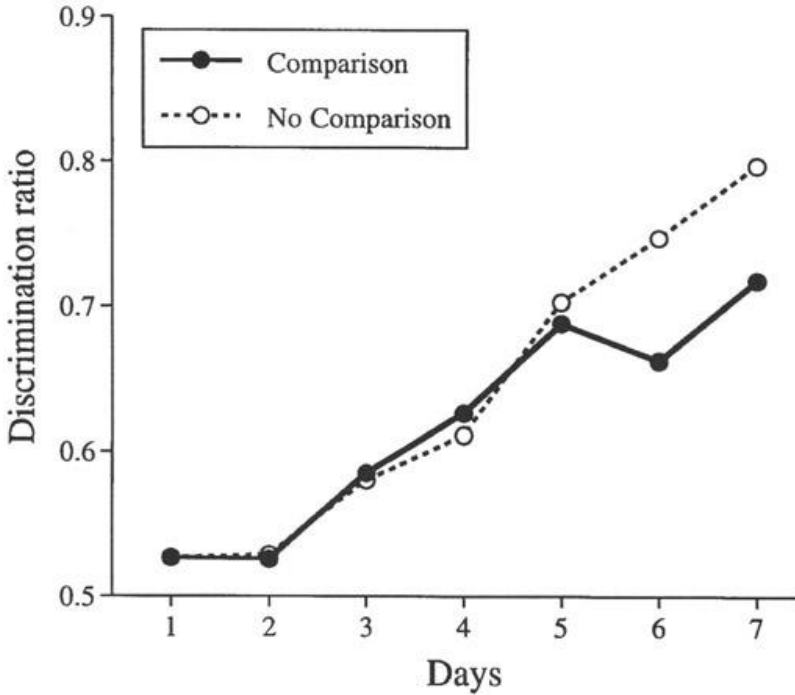
FIG. 9.12. Acquisition of the test discrimination by pigeons trained according to the procedures outlined in Fig. 9.11. The score used is the number of positive trials on which a response occurred over the total number of trials on which at least one response occurred.

The notion of comparison-induced stimulus differentiation suggests an alternative explanation. Suppose that, in the absence of an opportunity for comparison, subjects in Group NC tend to perceive Stimuli A
and B simply as "colors" whereas Group C, given the opportunity to compare, becomes sensitive to the distinguishing features of these stimuli, a and b. Only in the latter group, therefore, will it be possible for an excitatory

association to be formed between a and b, and only this group will suffer the negative transfer that this association will bring to the discrimination task. The relatively poor performance of Group C can thus be explained on these grounds alone, without any need to postulate an additional inhibitory learning process.
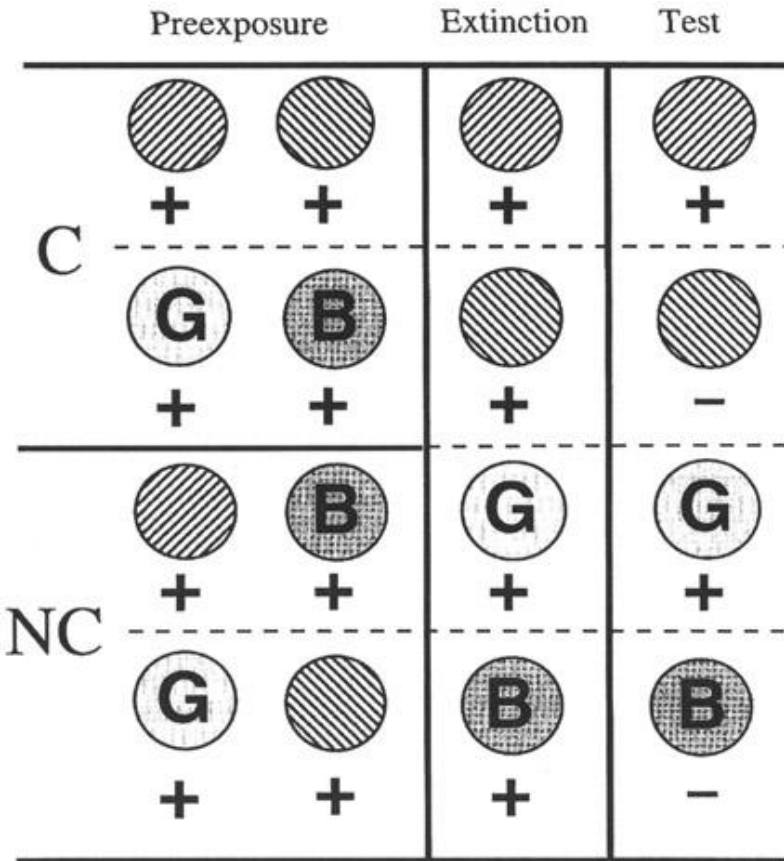

FIG. 9.13. Experimental design, modified from that shown in Fig. 9.11, in which a further phase of training was inserted

between preexposure and the test. In this (extinction) phase, all four stimuli were presented singly on the center key and all four were associated with reward. (The term extinction refers to the notion that within-display associations formed during preexposure might be expected to extinguish during this phase.) G = green keylight; B = blue keylight; + = food reward; − = no reward.

In a further experiment, Mondragon and I (Hall & Mondragon, 1999) attempted to discriminate between these alternatives. As in the previous experiment, pigeons in Groups C and NC were given nondifferentially reinforced preexposure to colors and shapes (see Fig. 9.13) and were subsequently tested on a successive discrimination task involving

these same stimuli. Between these two stages, however, a further phase of training (labeled extinction in Fig. 9.13) was given. This consisted of four sessions each of which contained 20 (reinforced) presentations of each of the four stimuli presented individually on the center key. This procedure was intended to bring about the extinction of excitatory associations formed between the simultaneously presented stimuli during preexposure. It should, however, be without effect on any inhibitory associations formed during preexposure (see Zimmer-Hart & Rescorla, 1974); it may, indeed, even strengthen inhibitory associations between the unique elements of A and B and of X and Y, as a will still predict the absence of b (and vice versa) and x the absence of y (and vice versa). If the superiority of Group NC observed in the previous experiment depends on these inhibitory associations, then the same result should be obtained in this study. However, if the previous result depends on the existence of excitatory associations between A and B and

between X and Y, the extinction treatment introduced in this version of the experiment should abolish the effect.

The results of the test discrimination, shown in Fig. 9.14, are quite the reverse of those of our first experiment. We now find that Group C learns the discrimination more readily than Group NC. The number of trials necessary to reach an overall criterion of .75 was 260 for Group C and 450 for Group NC, a difference that was statistically reliable ($p < .05$). This outcome is not that predicted by the inhibitory associations theory. It can, however, be accommodated by the alternative account. According to that account, excitatory associations are able to form between the unique features of simultaneously presented similar stimuli in Group C precisely because this mode of presentation allows differentiation to occur, rendering the animal sensitive to these features. Extinguishing these associations will not only eliminate their deleterious effect on the performance of Group C; it will also allow the facilitatory effects of the differentiation process to show through. The results shown in Fig. 9.14 reflect the operation of a stimulus differentiation process in perceptual learning.

Conclusions

The various experimental findings summarized in this chapter allow the general conclusion (admittedly with a large number of qualifications) that prior exposure to one or both of a pair of similar stimuli can reduce generalization (or facilitate discrimination) between them. Many of these findings can be explained in terms of standard associative mechanisms

(including among these subsidiary but related processes like latent inhibition). There remains, however, a stubborn residue of observations that resists explanation in these terms. These seem to indicate that mere exposure to a stimulus can allow differentiation to occur, so that the animal becomes more sensitive to unique features of that stimulus and less sensitive to features that it holds in common with other similar stimuli.
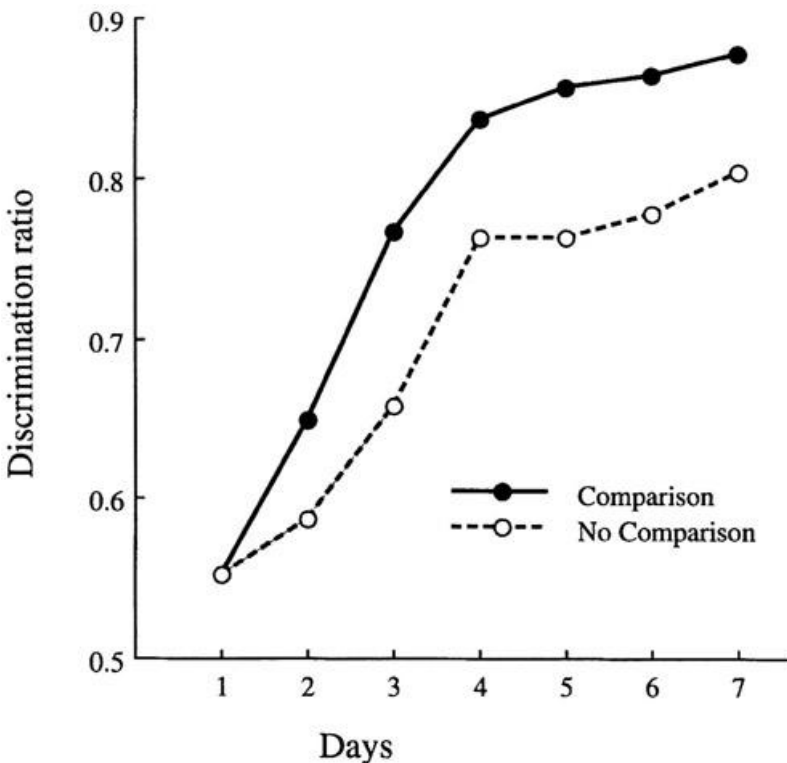

FIG. 9.14. Acquisition of the test discrimination by pigeons trained according to the procedures outlined in Fig. 9.13. The score used is the number of positive trials on which a

response occurred over the total number of trials on which at least one response occurred.

We (the work is being done in collaboration with Killcross) recently started to attempt to develop an account of the mechanism by which differentiation might occur. Our starting point is the phenomenon of habituation, which we interpret as showing that exposure to a stimulus will reduce its effectiveness, making that stimulus less able to elicit responding and also less likely to be learned about. Next we assume that the animal's processing system is of limited capacity so that often not all the elements that constitute a stimulus will be sampled when that stimulus is presented. We further assume that, for stimuli of the sort used in the experiments

discussed here, the common (c) elements are likely to be more salient than the unique (a or b) elements. On the first presentation of A (or B), therefore, it is the c elements that will be sampled. If the trial with A is reinforced, generalization to B in these circumstances will be substantial. Exposure to a stimulus will allow habituation to occur, but for any given element to undergo habituation, it must first be sampled. It follows that the c elements will undergo habituation before the unique elements. It then becomes a simple matter, given certain assumptions about the limited capacity of the animal's processing system, to predict that the effectiveness of the unique elements can come to exceed that of the initially more salient common elements. Preexposure to A will thus mean that its a elements are especially likely to be learned about on a subsequent conditioning trial, and generalization to B (which depends on the c elements acquiring strength) will be limited (e.g., Honey, 1990). Preexposure to B will mean that its c elements are less likely

to be sampled on the test trial and generalization will again be restricted (e.g., Honey & Hall, 1989b). With preexposure to A and B, both these effects will operate and little generalization should occur (e.g., Symonds & Hall, 1995). Evidently a theory of this general sort can be made to encompass the basic facts of perceptual learning with relative ease.

We are currently attempting to develop a formal theory of perceptual learning along the lines outlined in the preceding paragraph. This is not the place to go into details of the formalization and several matters still remain to be resolved (e.g., how the phenomenon referred to as unitization should be dealt with; why the effects of preexposure to two stimuli should depend on the way in which they are scheduled). The point of presenting this brief outline is not to offer a precise explanation of any particular phenomenon. Rather, it is to make clear (in spite of the impression sometimes generated by Gibson's [1969] pronouncements on the topic) that there is not necessarily anything mysterious about the notion of stimulus differentiation. The differentiation process can be modeled by a mechanism that does little more than combine standard notions of habituation with the widely accepted tenets of stimulus-sampling theory. We have reason to hope that this simple model, when appropriately developed, will prove able to accommodate more than just the basic facts of perceptual learning—the attempt to extend the model to more complex phenomena is currently at the focus of our theoretical endeavors.

Acknowledgments

Note

1 The lack of a difference between these two groups suggests that latent inhibition effects probably played only a minor role in this experiment (I have already suggested that conditioning parameters employed by Symonds & Hall, 1995, were sufficiently powerful that even preexposed stimulus elements might have acquired a full measure of associative strength). However, the critical point, for present purposes, is not the absolute size of any latent inhibition effect but the fact that it should be the same size in the two preexposed groups.

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