

CHAPTER 1

*Associative Structures in Pavlovian
and Instrumental Conditioning*

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INTRODUCTION

In the most basic of conditioning procedures, the experimental subject (usually an animal, but sometimes a human participant) experiences two events in close temporal conjunction. In Pavlovian conditioning, one stimulus (the unconditioned stimulus, US) occurs along with (usually shortly after) the presentation of some other (the conditioned stimulus, CS); in instrumental conditioning, a stimulus (or outcome, O) is forthcoming after the animal has emitted some specified pattern of behavior (or response, R). That is, in both procedures, the experimenter arranges an association between events in the world. What could be more natural then, than to attempt to explain the resulting changes in the animal's behavior in terms of a mechanism that allows the animal to form some central representation of the association between the events that it experiences? Indeed, the dominant account of conditioning over the last 100 years (since the pioneering work of Pavlov and of Thorndike at the turn of the 19th century) has been associative.

Specific accounts differ in many ways (as we shall see), but the central assumption of all associative analyses of conditioning has been that the effects observed can be explained in

terms of the operation of a *conceptual nervous system* that consists of entities (to be referred to as *nodes*) among which links can form as a result of the training procedures employed in conditioning experiments. The existence of a link allows activity in one node to modify the activity occurring in another node to which it has become connected. My task in this chapter is to review what conditioning experiments have revealed about the structure of this conceptual nervous system. At the most general level, of course, the structure is assumed (i.e., we have assumed a set of nodes interconnected by links), but what characterizes the nodes involved in any given conditioning procedure and the pattern of interconnections that forms among them remains unspecified.

These questions concerning structure cannot be wholly divorced from consideration of the functional properties of the system. In particular, what is assumed about the nature of the activity engendered in a node (as a consequence of its being activated by way of an associative link) turns out to have important implications for interpretations of associative structure. My starting position will be the assumption that activity engendered in a stimulus node via an associative link is functionally identical to that produced by direct application of the relevant stimulus itself. It will

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soon become evident, however, that this assumption can be hard to sustain (or at least that, in order to do so, it is necessary to postulate associative structures of possibly undue complexity). This issue will need to be dealt with in the course of my discussion. For the most part, however, it will be possible to sidestep any detailed discussion of a further question about the functioning of the system: What conditions must be met for an association to be formed? Many alternative answers have been given to this question, and debate about the relative merits of these alternatives has dominated the work of some associative learning theorists over the last 30 years. For present purposes, I will simply assume that an associative link between two nodes can form (or changes in strength can occur) when both nodes are concurrently activated. This is a gross oversimplification (as will be revealed by reading of Chap. 2, this volume); but it can be justified (see Hall, 1994), and it will serve to get the discussion of structural issues under way.

The rest of this chapter is divided into three main sections. The first is concerned with simple excitatory conditioning. “Simple” here refers not to the nature of the associative structures involved (which can be surprisingly involved) but to the basic experimental procedures employed. These are, for Pavlovian conditioning, the case in which a single CS reliably precedes the occurrence of a US and for instrumental conditioning, the case in which a given response reliably results in a given outcome. Unsurprisingly, it turns out to be necessary to consider more complex excitatory conditioning experiments in order to work out what is going on in these cases.

The second section deals with simple inhibitory conditioning. Again, the qualifier “simple” refers to the basic procedure, the effects of which are to be explained. This is the procedure in which the association between relevant events is discontinued—by present-

ing the CS without the US in the Pavlovian case, or by allowing the response to occur without outcome in the instrumental case (i.e., the procedure known as *extinction*). Again, it will be necessary to consider more elaborate procedures, including some that involve what I shall refer to as complex conditioning.

The third section directly addresses the issue of complex conditioning, in which the critical event (the CS or the response) cannot reliably predict what will follow (whether this be another event or its omission). Rather, the nature of the event that follows the CS (Pavlovian) or the response (instrumental) varies according to circumstances. Examples of such *conditional* training include procedures in which CS X is followed by the US only when it is presented in compound with CS A but not when it is presented alone (to be symbolized henceforth as AX+/X-) and those in which a response produces an outcome only when a given stimulus is present but not otherwise (instrumental discriminative training).

The final section of the chapter briefly reviews the ways in which the experimental work described in the other sections of the chapter requires us to modify or elaborate on those assumptions about the structure and functioning of the conceptual nervous system that we have taken as our starting point.

SIMPLE EXCITATORY CONDITIONING

Pavlovian Conditioning

In this procedure the experimenter manipulates two events (the CS and the US), of which the US commonly elicits some overt response, the unconditioned response (UR). Associative analysis begins by assuming a node for each event. Stimulus nodes will be activated by the presentation of the relevant stimulus;

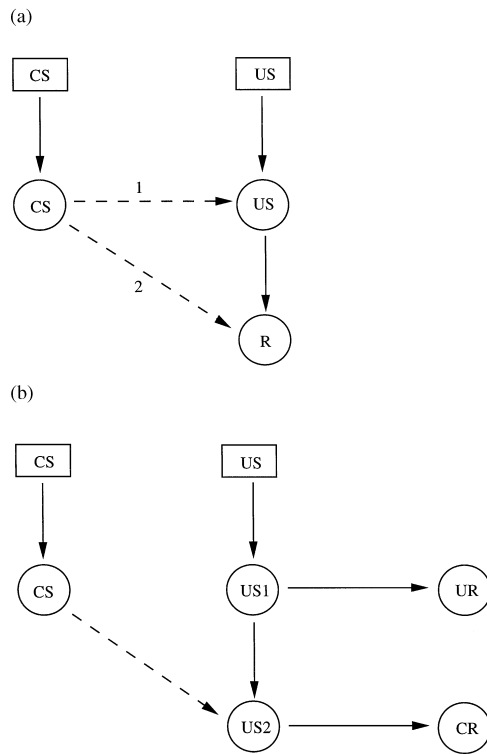


Figure 1.1 Excitatory Pavlovian conditioning. NOTE: (a) Possible associative structures for excitatory Pavlovian conditioning. (b) An elaboration expressing Wagner’s (e.g., 1981) suggestion that conditioned and unconditioned stimuli might engender different states. Circles represent nodes in a conceptual nervous system; rectangles represent environmental events. Lines connecting nodes suggest how activity in one node can influence activity in another; solid lines indicate intrinsic links, and dashed lines indicate links that can be strengthened or weakened by experience. An arrow indicates that the action of the link is to engender activity in the target node. CS: conditioned stimulus; US: unconditioned stimulus; R: response; UR: unconditioned response; CR: conditioned response.

a response indicates activity in the node responsible for that behavior. These nodes are depicted in Figure 1.1a, in which the solid line indicates the presumed inherent excitatory link between the US node and the node responsible for organizing emission of the UR. The assumption that concurrent activation of

nodes allows the formation of links between them means that the connections indicated by the dashed lines could form during the course of conditioning. One (labeled 1 in the figure) allows presentation of the CS to activate the US node in the absence of the US itself; this may be described as an S-S theory of conditioning. The other (link 2) allows the CS directly to evoke the behavior that is otherwise called a UR (an S-R theory). The change that occurs in the properties of the CS (its acquired ability to evoke a conditioned response, CR) could reflect the operation of either or both of these links. The relevant experimental evidence, to be reviewed next, does not allow any simple choice between these alternatives but leads to the development of a more complex, but also more interesting, picture.

The Form of the Conditioned Response

Although widely discussed in this context, the form of the CR that develops with CS-US pairings turns out to supply little information about the underlying associative structure; accordingly, this matter can be dealt with very briefly here. It has been noted that the CR and UR are sometimes very similar (even, in some preparations, indistinguishable, e.g., Culler, Finch, Girden, & Brogden, 1935), a finding that has been taken to support the view that conditioning establishes link 2, which allows the CS direct access to the UR node. As will be evident from Figure 1.1a, however, link 1 also allows access to the UR node by a route that is only marginally less direct. Both interpretations can accommodate the fact that the form of the CR may match that of the UR. Furthermore, neither is much discomforted by those cases in which the CR differs from the UR. For example, in the Pavlovian training procedure widely used for pigeons (and known as autoshaping), the UR is pecking at food in a food tray, whereas the CR is pecking elsewhere (at a light that has previously signaled the delivery of food). This CR appears to be a

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blending of the UR with a (usually subthreshold) response tendency governed by the key light. Although the details need to be specified, it is clearly open to the theorist to postulate the existence of an output-controlling mechanism that takes its input not only from the UR node shown in the figure but also from any other response node that may be activated at the same time (see Holland, 1977, for a full discussion of this possibility).

Seemingly more problematic are cases in which the CR appears to be quite different from, even antagonistic to, the UR. A possible example is the ability of a CS that has signaled an injection of morphine to evoke hyperalgesia, the UR to morphine being analgesia (see, e.g., Siegel, 1975). Partly to deal with such effects, Wagner (e.g., 1981) introduced a version of the S-S theory that abandoned the assumption that the activation induced in a node by an associative link is functionally the same as that produced by direct application of the stimulus. The state evoked by the stimulus itself was referred to as being one of primary activation (the A1 state) and was assumed to be qualitatively different from the state of secondary activation (the A2 state) produced by the associative link. It is worth noting that it may be possible to express this general notion without the need to postulate that a given node can experience different types of activation. In the version shown in Figure 1.1b, the node directly activated by the US (US1) is assumed to activate a further node (US2), and it is with this latter node that the CS is assumed to form an association.

However it is formalized, Wagner's proposal turns out to have a range of far-reaching implications that are not discussed further here. For present purposes, its importance is that it allows the possibility that the CR and UR might differ in form. In some response systems, the response elicited by the A2 state (or by the US1 node) may be the same as that evoked by the A1 state (by the US2 node), but

in other systems, opponent principles may apply. What it does not do, however, is require us to accept the S-S account. Although no such theory has been explicitly developed, it would be quite possible for a proponent of the S-R account to adopt the analogous proposal that the activity evoked in the UR node by way of link 2 (Figure 1.1a) is qualitatively different from that evoked by the US itself. Choice between the alternative accounts requires evidence from other sources.

Conditioning with No UR

It is well established that classical conditioning can occur when the UR normally evoked by the US is prevented from occurring. For example, Zentall and Hogan (1975) reported that pigeons given pairings of a key-light CS and a food US would develop the CR of pecking at the key even when access to the food (and thus the normal UR of pecking and eating) was prevented by means of a transparent screen. This sort of observation argues against a literal interpretation of the S-R account but does not constitute decisive disproof of the general notion. Physically preventing the occurrence of the overt UR does not necessarily mean the absence of activity in the central node responsible for organizing the (attempted) emission of that response. Accordingly, an S-R connection (link 2 of Figure 1.1a) could still form in these circumstances. More informative on this matter are experiments that make use of the two-stage conditioning procedures depicted in Figures 1.2 and 1.3.

In the procedure known as *sensory preconditioning* (Brogden, 1939; see also Chap. 2, this volume), no attempt is made to suppress the UR; rather, evidence is sought for conditioning when the events involved are such that no overt UR is evident in the first place. In the first stage of this three-stage procedure, the subjects receive pairings of two stimuli (A and B in Figure 1.2a), as in standard classical conditioning, but both events are neutral (i.e.,

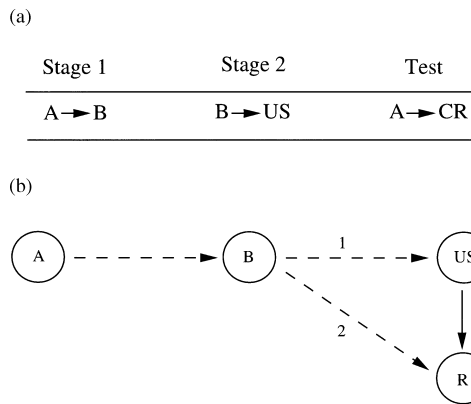


Figure 1.2 Sensory preconditioning.
 NOTE: (a) Design of an experiment on sensory preconditioning; A and B represent stimuli. (b) Possible associative structures produced by this training procedure. Conventions and other abbreviations are as given for Figure 1.1.

neither evokes an obvious UR). Any association formed between these events may be assumed to be S-S in nature. The rest of the training procedure is designed to allow this association to show itself in behavior. In the second phase of training, one stimulus (B) is paired with an orthodox, motivationally sig-

nificant US so that a CR develops. Upon testing, it is found that stimulus A is also capable of evoking the CR to some degree (e.g., Brogden, 1939; Prewitt, 1967; Rescorla & Cunningham, 1978). This outcome is readily explained in terms of the *associative chain*, depicted in Figure 1.2b. By virtue of the (S-S) link between A and B, stimulus A, when presented during the test, is able to activate the node for stimulus B, which has itself acquired the power to evoke a CR. It may be noted that this procedure is silent about the mechanism by which B acquires this power; both S-R and S-S learning could occur during phase two, and both links 1 and 2 are shown in the figure. It does show, however, that S-S learning *can* occur (between A and B in phase 1); parsimony may justify the presumption that it will also occur (between B and US) in phase two.

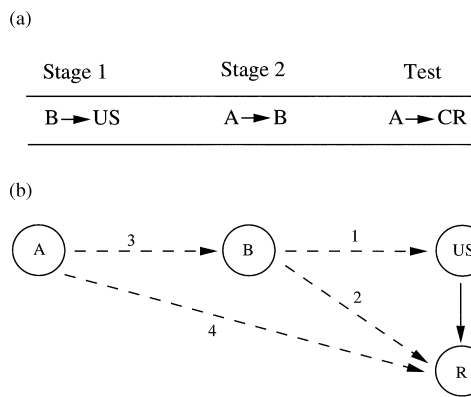


Figure 1.3 Second-order conditioning.
 NOTE: (a) Design of an experiment on second-order conditioning; A and B represent stimuli. (b) Possible associative structures produced by this training procedure. Conventions and other abbreviations are as given for Figure 1.1.

In the *second-order conditioning* procedure of Figure 1.3, the order of the first two stages of sensory preconditioning is reversed. In stage one, subjects receive standard (first-order) conditioning, and as a result CS B may come to evoke a CR (either by way of an S-S connection, link 1, an S-R connection, link 2, or both; see Figure 1.3b). The second stage consists of pairing a new CS (A) with the pre-trained CS B. The outcome is that A acquires the power to evoke the CR. This result can be explained in both S-R and S-S terms. The former account assumes that during stage-two training a link is formed between stimulus A and the response that B is able to evoke, by virtue of its stage-one training (link 4 in the figure). According to the latter, an A-B link is formed during stage two (link 3 in the figure) so that A, when presented alone during the test, is able to activate the B representation and hence evoke the CR (by way of link 1, link 2, or both).

In itself, therefore, the phenomenon of second-order conditioning does not speak to the theoretical issue of concern here. Its

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importance in this context is that there are some instances of successful second-order conditioning in which the first-order stage does not establish a CR to stimulus B (or, at least, does not establish the CR finally elicited by A during the test). Nairne and Rescorla (1981) conducted a second-order conditioning experiment with pigeons in which stimulus B was a burst of noise paired with food in stage one, and stimulus A the illumination of a response key. The birds acquired the response of pecking at stimulus A, although the noise did not evoke a directed pecking response. It seems that link 4 cannot form in these circumstances (as link 2 is ineffective), prompting the conclusion that the critical link is directly between the representations of A and B. Before accepting this conclusion, however, we should acknowledge the viability of an alternative interpretation. Although the noise does not elicit overt pecking, it will undoubtedly acquire the ability to elicit other, covert, responses—the set of emotional or affective responses appropriate to the imminent delivery of food. An S-R link formed in stage two would allow stimulus A to evoke these same responses (although additional assumptions are needed to explain why these responses should come to show themselves in key pecking). The issue of the conditioning of emotional responses or states is taken up in the following sections.

Revaluation of the US

In the sensory preconditioning procedure, the first stage of training allows the formation of an association between two neutral stimuli. The second stage of training gives value to one of these stimuli (by pairing it with a motivationally significant event), and the consequences for the other are observed. This same general technique can be applied to give information about the nature of the association formed between an orthodox CS and US. For example, Holland and Straub (1979) gave rats pairings of a noise and food in a first stage of

training, sufficient to establish the CR of approaching the site of food delivery in the presence of the noise. In a second phase of training carried out in the home cage, the rats ate food pellets of the sort used as the US before receiving a nausea-inducing injection of a lithium salt (Li). This procedure was effective in devaluing the US, as evidenced by a reduction in the willingness of the rats to consume these pellets. A final test conducted in the original conditioning apparatus revealed a substantial reduction in the frequency of the CR to the noise, compared with the responding of rats that had not experienced the devaluation treatment. This outcome is not to be expected on the basis of the S-R analysis—there is no reason why an association between the CS and a response elicited by a US should be affected by a subsequent change in the value of that US. On the other hand, if conditioned responding depends on the ability of the CS to activate a representation of the US, then a sensitivity to changes in the nature of that representation is just what would be expected.

Sensitivity to postconditioning changes in the value of the US has been demonstrated a number of times in a variety of conditioning procedures (e.g., Fudim, 1978; Holland & Rescorla, 1975; Rescorla, 1973a, 1974), and it constitutes the best evidence for the widespread importance of the S-S association in classical conditioning. This is not to say, however, that an S-S link underlies all instances of conditioned responding or that it is the sole source of the CR in those preparations in which it is known to play a role. Holland and Straub's (1979) experiment is informative on both these points. With respect to the first, in addition to measuring food-cup approach, Holland and Straub measured another CR: the increase in general activity that develops in the presence of an auditory signal for food. This response was present in full strength during the test and thus must depend on some mechanism that is not sensitive to the food

devaluation procedure they used. With respect to the second point, it is noteworthy that in Holland and Straub's experiment, although the devaluation procedure appeared to be completely effective (several food-LiCl pairings were given and consumption of the pellets declined practically to zero), the conditioned food-cup approach in the test phase was not totally abolished. This observation prompts the conclusion that some mechanism other than that embodied in the S-S link plays a part in generating this CR—that an S-R link has also been established.

Further evidence supporting the view that no single associative structure is responsible for all cases of conditioning comes from a reconsideration of second-order conditioning. As we have already seen, the basic effect can be explained both in S-R terms (link 4 of Figure 1.3), or in S-S terms (link 3). A version of the devaluation procedure can again be used to choose between these possibilities. The S-S account implies that stimulus A is able to evoke the CR only because its associate, B, has previously acquired conditioned properties. Removing these should eliminate the CR to A; that is a phase of extinction, in which B is presented alone until its CR disappears, interposed between stage two and the test, should abolish a second-order conditioning effect based on an S-S association. For the S-R account, on the other hand, stimulus B will have done its job (by evoking a response) during stage one, and the ability of A to evoke the CR should be impervious to subsequent changes in the value of B.

The effects of extinguishing the first-order CS on the second-order CR have been investigated several times and the results have been mixed. Some (e.g., Leyland, 1977; Rashotte, Griffin, & Sisk, 1977; Rescorla, 1979a) have found significantly reduced responding to A after extinction of B; others (e.g., Nairne & Rescorla, 1981; Rizley & Rescorla, 1972) that responding to A is unaffected. We must con-

clude, following the logic of the argument set out in the preceding paragraph, that both S-S and S-R links can be formed; what remains to be determined is the nature of the circumstances that foster the formation of one type of link rather than the other. The full answer to this question is not yet clear, but it seems likely that the relative salience of the events involved will play a role (see Holland, 1985a). Consider the experiment by Rizley and Rescorla (1972) in which stimuli A and B were a light and a tone, and the US an electric shock. During stage two of the second-order conditioning procedure, therefore, the target stimulus A is paired with a B stimulus that lacks any salient immediate sensory properties but that, by virtue of its stage-one pairing with shock, is capable of evoking a powerful set of emotional (fear) responses. It is unsurprising then, that the S-R link should come to dominate in this training procedure. In the experiment by Leyland (1977), on the other hand, A and B were key lights, and the US the delivery of a small amount of food. If we may assume that for pigeons (Leyland's subjects), the presentation of a key light is a salient event, or at least, is more salient than the CRs it will evoke after being paired with food, then S-S learning can be expected to dominate in generating a second-order CR that is sensitive to devaluation of the first-order CS.

Sensory and Affective Aspects of the US

The analysis just offered for second-order conditioning provides a new perspective on the first-order case. The events used as traditional USs can also be seen as possessing both sensory and affective components (the latter being intrinsic, rather than acquired as a consequence of explicit training as in the second-order procedure). Thus the presentation of food must be assumed to activate not only a node or nodes representative of its visual properties, its taste, texture, and so on, but also some further node, in which activity

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corresponds to the presence of a positive affective state. Activation of each of these nodes can be assumed to elicit its own characteristic response—for instance, activation of a sensory node could result in a directed approach response whereas activation of the affective node might produce a state of enhanced autonomic activity. The simple picture of Figure 1.1a should be elaborated along the lines shown in Figure 1.4.

There are now four possible links to deal with and we must reconsider the evidence presented so far in light of this development. Interpretation of those cases in which US devaluation is effective is not much altered—this

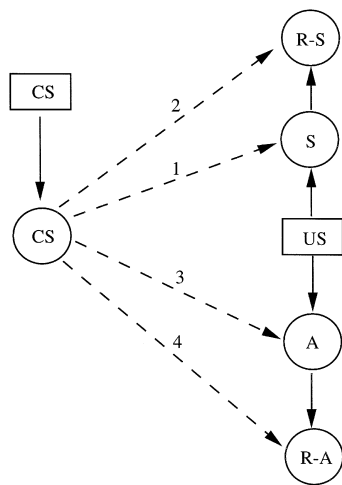


Figure 1.4 Associative structures for excitatory Pavlovian conditioning in which the sensory (S) and affective (A) properties of the US are represented by different nodes.

NOTE: R-S indicates a node responsible for generating responses specific to the particular sensory properties of the US; R-A indicates a node responsible for generating affective responses (an emotional state). Conventions and other abbreviations are as given for Figure 1.1. Although they are omitted from the figure for the sake of clarity, it may be supposed that links could also form between the various US nodes (e.g., a link between S and A would allow the sensory properties that characterize a foodstuff to evoke an affective state).

result tells us that an association has formed between the CS and some aspect of the US representation, meaning either or both of links 1 and 3 have been formed. For many of the procedures discussed so far, we cannot be sure which, although the nature of the CR can supply grounds for a plausible guess. In Rescorla's (1973a) experiment the CR that proved sensitive to US devaluation was the conditioned emotional response evoked by a signal for shock, a response that we may assume depends on learning about the affective properties of the US (i.e., on link 3). In the Holland and Straub (1979) experiment, however, the CR that was reduced by US devaluation was the response of approaching the food cup, a behavior that requires the animal to have encoded information about the sensory properties (location) of the US and thus implies the formation of link 1. (Sensory pre-conditioning provides even clearer evidence for the role of link 1—for an association between the CS and the sensory properties of the US—as the event that acts as the US does not possess affective properties.)

Complications arise, however, when it comes to cases in which US devaluation is ineffective; here the new possibilities introduced by Figure 1.4 render interpretation ambiguous. The persistence of responding after devaluation could indeed imply that the CR depends on one or both of the S-R links (links 2 and 4 in the figure). Alternatively, it could be that the devaluation manipulation affects only one aspect of the US representation, leaving the other still capable of evoking a response. If, for instance, food that has been associated with Li suffers a devaluation only of its sensory properties, then a CR based on link 1 in the figure would be lost, but a response controlled by the link between the CS and the affective node of the US (link 3 in the figure) would still be observable. The persistence of the general activity CR in the Holland and Straub (1979) experiment could thus reflect

the operation of an S-S link rather than S-R learning. As evidence of S-R learning in this experiment, it should be recognized that food-cup responding was not totally abolished by a devaluation procedure hypothesized to have rendered link 1 ineffective. Such directed responding could not be generated by links 3 and 4—but is what would be expected if the (S-R) link 2 had acquired some strength during initial training.

The picture emerging from this analysis is that, under appropriate circumstances, each of the potential links shown in Figure 1.4 is capable of being formed. What remains to be determined, however, is which links do in fact form in the course of any given standard first-order procedure. The discussion of second-order conditioning introduced the proposal that there might be competition among aspects of the US for association with the CS, and that salient affective aspects of the US might dominate learning at the expense of potential associations involving sensory aspects of the US. Given that the events used as USs in standard conditioning procedures are chosen because of their motivational significance, it seems possible that these procedures might favor emotional or affective conditioning (i.e., the formation of links 3 and 4) and fail to generate learning about the sensory aspects of the US (links 1 and 2). Evidence relevant to this proposal comes from experiments using the *blocking* design in which subjects receive initial training with CS A signaling the US, followed by a phase of training in which a compound stimulus, AB, precedes the same US. Blocking of conditioning to B in these circumstances has been taken to indicate that learning fails to occur when the outcome of the trial is unsurprising (being fully predicted in this case by the pretrained CS A). In the variant of this design that is relevant to our present concern, the US used in the compound phase of training retains the same affective value as that used in the first phase, but its sensory proper-

ties are changed. In a number of experiments (e.g., Bakal, Johnson, & Rescorla, 1974, who switched from shock to a loud noise; Ganesan & Pearce, 1988, who switched from food to water), the blocking effect has still been obtained. This outcome prompts the conclusion that the change in the nature of the US was unsurprising to the animal, thus the association(s) established during the initial phase of training with A involved only the affective, not the sensory, properties of the US.

But whatever is true for the training procedures just considered, it is clear that in other procedures the specific sensory attributes of the US are learned about. That a rabbit given eye-blink conditioning shows a CR only with the eye to which the US has been applied, proves that one of the sensory properties of the US (its location) plays a role in the associative structure established during conditioning. Betts, Brandon, and Wagner (1996) made just this point and went on to demonstrate that blocking did not occur when the compound CS signaled a shock to the other eye—this sensitivity to the change of location confirms that the original location must have been learned in the first stage of training. Interestingly, however, blocking *was* obtained when the response measured was not the eye blink itself, but an index of a CS-induced heightening in the animal's general level of emotional responsiveness. Evidently the animal had also learned in the first stage about the affective properties of the US (properties that do not change, whether the shock is given to the left or the right eye). This result prompts two conclusions. First, the fact that transreinforcer blocking sometimes occurs (as in the experiment by Bakal et al., 1974) does not necessarily imply that the subjects had failed to learn about the sensory properties of the US—rather it may indicate that the response measure used is one that is sensitive only to the association between the CS and the US's affective properties. Second, the

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results of Betts et al. demonstrate that learning about the affective properties of a US does not preclude learning about its sensory properties (or vice versa). Indeed, according to the influential theory of conditioning proposed by Konorski (1967, and developed by Wagner & Brandon, 1989), dual association formation is the norm, and establishment of the affective link constitutes a necessary background for the development of specific CRs controlled by association with specific sensory aspects of the US. In first-order conditioning, at least, the two associations appear to cooperate rather than compete (see also Gewirtz, Brandon, & Wagner, 1998).

Instrumental Conditioning

The associative analysis of instrumental conditioning begins by assuming three nodes, in which activity will co-occur in a standard training procedure. One (S) represents a node sensitive to the cues impinging on the animal when a response is performed (e.g., the visual cues arising from the lever in a Skinner box); activity in the response node (R) equates to performance of the target response (e.g., pressing the lever); another stimulus node (O) is activated by the presentation of the outcome (e.g., the delivery of a food pellet) generated by that response. My present concern is to determine the nature of the association that the R node might enter into. Figure 1.5 shows the two most obvious possibilities—a link between the R and O nodes, and a link between the S and R nodes—and the bulk of the discussion in this section will be concerned with the role of these two links in determining instrumental performance. Also shown in the figure is the link between S and O that might also be expected to form on the basis of the Pavlovian conditioning principles described above (the O being construed as a Pavlovian US, and the set of stimuli that accompany it as a CS). The possible contribution of this

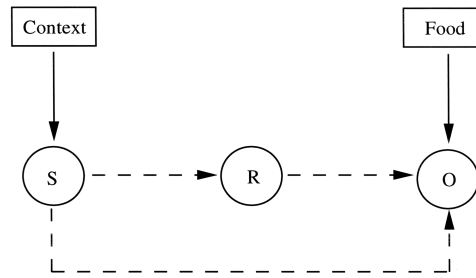


Figure 1.5 A possible associative structure for excitatory instrumental conditioning.

NOTE: S: stimulus; R: response; O: outcome. Conventions and other abbreviations are as given for Figure 1.1.

link to instrumental performance cannot be neglected.

Inadequacy of the S-R Interpretation

The strength of the notion that instrumental training establishes an S-R association lies in the fact that it provides a direct explanation for the behavior observed—once formed, the link ensures that perception of the relevant stimuli (e.g., lever cues) will automatically evoke the target response (the lever press). Additional theorizing is, of course, necessary to explain why it is that this S-R connection should form rather than some other, and the usual solution has been to adopt some version of Thorndike's law of effect, the principle that a rewarding outcome will *reinforce* an association that it immediately follows. It will be noted that, according to this account, the outcome does not itself enter any associative structure, and herein lies the weakness of the theory—for it is a simple matter to demonstrate that outcomes do more than simply reinforce S-R links. Two observations will suffice to make this point.

First, there is evidence suggesting that animals acquire information about the relationship between their response and the outcome. In particular, instrumental performance is sensitive to the validity of the response as a

predictor of the outcome (the so-called *contingency* effect). The rate at which a thirsty rat will lever-press for the delivery of water will decline if “free” water deliveries are also available (e.g., Hammond, 1980). This makes sense if the rate of response is taken to depend on the strength of a R-O link (standard theories of association formation, e.g., Rescorla & Wagner, 1972, readily predict a weakened association in these conditions). According to S-R theory, however, what matters in establishing and maintaining performance is solely the contiguous occurrence of the response and the outcome, and, given that response-contingent outcomes continue to be available, the addition of the free outcomes should be without effect.

Second, there is evidence suggesting that animals acquire information about the nature of the outcome generated by their responding. It has long been known that if the outcome is changed during the course of training, say from a large to a small amount of food, the vigor of the animal’s response will change immediately (as in Crespi’s, 1942, negative contrast effect). Such sensitivity to change must mean that the properties (in this case, the size) of the original reward had been encoded in some way. Essentially the same conclusion is supported by more recent experiments that make use of the (now familiar) technique of postconditioning revaluation of the reinforcer. Rats trained to press a lever for a given type of food will, if that food is subsequently paired with an injection of Li, show a lowered rate of response on a test in which the lever is again made available (Adams & Dickinson, 1981; Colwill & Rescorla, 1985a). (No outcomes are delivered on the test, ensuring that the result is not a consequence of some direct response to the now-aversive food.) Other procedures for revaluing the outcome confirm the findings obtained with the food-aversion technique. Colwill and Rescorla (1985a; see also Dickinson, 1987) have shown that if, just

prior to the test, rats are given free access to the type of food that was used as the outcome in initial training, their willingness to make the response that had previously produced that outcome is significantly reduced. Also, Dickinson and Dawson (1987a, Experiment 1) found that rats trained to respond for food pellets when hungry showed a low rate of response when tested *thirsty* (as compared to a separate group of rats trained to respond for a sucrose solution, an event that presumably retains its value with the change from hunger to thirst. In all of these studies, responding appears to be determined by the current value of the outcome—which is consistent with the idea that information about the nature of the outcome has been encoded in the associative structure that determines performance, but is not consistent with an S-R theory that holds that the sole role of the outcome is to reinforce the S-R link in initial training.

The Role of the S-O Association

Establishing the inadequacy of the simple S-R account does not demonstrate the validity of the alternative R-O account. The analysis so far disregards the possibility that the S-O link of Figure 1.5 might also form during instrumental conditioning. Allowing that Pavlovian conditioning can go on alongside S-R learning may provide an explanation for the phenomena just discussed. The contingency effect would be explained if it was supposed that delivering free outcomes during instrumental training enhances the strength of a context-outcome association, and that an effect of this association is an increase in the likelihood of CRs (such as approaching the site at which the outcome is delivered) at the expense of lever pressing. The disruption of behavior evident in the Crespi effect could reflect the emotional response to an expectation about reward size, which is based on an association between the cues that constitute the training context and the reward presented in the first stage of

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training. Finally, devaluing an outcome will, as we have already seen, often reduce the effectiveness of a CS in evoking its CR. To the extent that a classically conditioned emotional state plays a role in energizing instrumental responding (a position adopted by many theorists, see Rescorla & Solomon, 1967), such devaluation might be predicted reduce the rate at which the instrumental response is performed.

This last suggestion is more than a theoretical possibility, as a further study (conducted by Dickinson and Dawson, 1987a, Experiment 2) of the effects of a motivational shift demonstrates. In this experiment, the rats were trained to perform (when hungry) two different responses in the same apparatus, one for a food pellet outcome, the other for sucrose solution. This within-subject procedure allows for the formation of associations between the contextual cues and both outcomes. When tested under thirst, the rats showed low rates of response, and these rates did not differ for the two responses. Thus, by this measure, the rats evidenced no knowledge of the relationship between a given response and its particular outcome; rather they simply showed an overall reduction in vigor, which is to be expected if a Pavlovian, or context-food, association was no longer contributing to the emotional state that energizes the behavior (see also Dickinson & Dawson, 1987b, and Chap. 12, this volume).

The Role of the R-O Association

For evidence that animals are sensitive to the R-O relation, it is necessary to demonstrate an effect that is selective to a particular R-O combination. Although the procedure used by Dickinson and Dawson (1987a) failed to reveal such selectivity, other procedures have been more successful. In a study of the contingency effect, Dickinson and Mulatero (1989; see also Colwill & Rescorla, 1986) trained rats to respond on two levers, each generating a different outcome. The introduction of free

outcomes of a given type resulted in a decline in responding that was particularly marked on the lever that was associated with that food-type. Colwill and Rescorla (1985a) report an analogous effect in a study using the outcome-devaluation technique. Again initial training was given in which two different responses (this time, pressing a lever and pulling a chain) produced different outcomes. Devaluing one of these outcomes by means of toxin injections produced a selective effect. When given access to the lever and the chain in a final test, given in extinction, the rats showed a reduced rate of response on the manipulandum that had been associated with the now-devalued outcome.

Although these results fit well with the proposal that instrumental training endows the animal with information about R-O relationships, an explanation in terms of S-O learning may still be possible. The training context does not constitute a single, simple stimulus, and it is possible that a range of S-O associations might be formed. For example, in the Colwill and Rescorla study, it is likely that cues arising from the chain, being closely associated with the outcome generated by the chain-pull, will form a particularly strong association with that outcome, whereas lever cues will be more closely associated with the outcome generated by the lever press. Devaluing one outcome could, therefore, according to standard Pavlovian principles, reduce the animal's tendency to emit the CR of approaching cues associated with that outcome. This, in itself, might be enough to reduce the likelihood of a particular response. Before we accept the notion of R-O learning, we should find reasons to discount this alternative interpretation of the results. Two lines of evidence will be considered.

Dickinson, Campos, Varga, and Balleine (1996; see also Colwill & Rescorla, 1986) adopted a strategy of looking for a response-selective devaluation effect that could not be

explained in terms of associations between contextual cues and the outcome. They trained rats with a single manipulandum, a rod, which produced a food pellet when pushed in one direction and provided access to a starch solution when pushed in the other direction. Devaluing one of these outcomes (by allowing free access to it before the test) was found to have a selective effect—responses of the type that had previously produced the preferred outcome were suppressed. Given that the cues arising from the manipulandum will be equally associated with both the starch and the pellet outcomes, it is difficult for any straightforward interpretation of the S-O analysis to accommodate these results—any reduction in the tendency to approach the manipulandum would be expected to influence both of the trained responses.

The second line of evidence comes from studies that attempt a direct evaluation of the properties of the S-O association that is assumed to be formed during instrumental training. This is most readily done in experiments that employ an explicit *discriminative stimulus* (Sd), a cue in the presence of which generates responses that are effective in producing the outcome (responses in the absence of the cue being ineffective). The control acquired by such a stimulus (the animal will come to respond only when it is present) could, in principle, reflect the influence of an association between the discriminative stimulus and the outcome, but an experiment by Colwill and Rescorla (1988) provides reasons for doubting this. In this study, rats received training with two cues, one trained as an Sd, the other simply paired with an outcome without any response requirement (i.e., established as a Pavlovian CS). Presenting these cues in a subsequent test phase during which the rats were performing a new, separately trained, instrumental response produced changes in responding, but the pattern of change evoked by the Sd was different from that evoked by

the CS. This is not what would be expected if the Sd's influence depended on its direct, Pavlovian association with the outcome. Further evidence that Sds and CSs are not interchangeable (as the hypothesis under consideration requires) comes from a study by Holman and Mackintosh (1981) that made use of the blocking paradigm. They demonstrated that training stimulus A as an Sd would block the development of control by B when an AB compound was subsequently trained as the Sd, but that blocking did not occur when A was trained as a CS in the first stage. Similarly, when the compound (AB) training stage involved Pavlovian conditioning, blocking was found when A was trained initially as a CS, but not when it was trained as an Sd.

This evidence that instrumental conditioning will not endow an Sd with powerful Pavlovian properties is enough in itself to undermine the proposal that the effects described earlier in this section should be explained in terms of the operation of S-O associations, thus leaving the field open to acceptance of the R-O alternative. Consideration of why it should be that an Sd makes a poor CS offers a positive reason to adopt this alternative. However it is to be explained (see Chap. 2, this volume), the phenomenon of *cue competition* is well established in Pavlovian learning. When two events are available as potential CSs, conditioning will occur more readily to the one that correlates better with the reinforcer—and will do so at the expense of one that does not correlate as well. Instrumental conditioning may similarly be construed as involving two events in competition for association with the reinforcer. In this case, the two events are the response and the Sd; and since the former correlates more directly with the outcome than the latter (responses in the presence of the Sd regularly produce reinforcement whereas, should the animal fail to respond, the Sd will be experienced in the absence of reinforcement), a markedly strong association cannot

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be expected to form between Sd and outcome. Thus the failure of the Sd to function fully as a CS can be explained, provided we adopt a theoretical interpretation of instrumental learning that presupposes the reality of R-O learning. What remains to be explained is how Sds exert the control they do, given that it is not by way of their Pavlovian properties. This matter is taken up in the section on complex conditioning.

The Role of the S-R Association

An account in terms of S-R associations cannot explain the results described above (even if it is supplemented by the suggestion that S-O associations may also play a role). This does not mean, however, that S-R associations are not formed (alongside S-O and R-O associations) during instrumental training. In our discussion of Pavlovian conditioning, we allowed that the contiguous activation of a stimulus node and a response node might produce an S-R link, and since instrumental procedures also ensure the co-occurrence of activity in S and R nodes, it seems reasonable to presume that the S-R link will form in this case too. But direct evidence to support this presumption is hard to come by.

Seemingly the most obvious piece of supporting evidence is that devaluation procedures are not wholly effective, as was true for Pavlovian conditioning. Given a choice between two levers, rats will respond less readily on that associated with a now-devalued outcome, but responding does still occur (e.g., Colwill & Rescorla, 1985a). This residual responding could represent the contribution of a component (based on the S-R link) that will not be sensitive to devaluation procedures. It is a problem for this interpretation, however, that residual responding after reward devaluation is almost totally abolished by a small change in procedure (direct delivery of the reward into the rat's mouth; Colwill & Rescorla, 1990a) that does not affect the number of

S-R pairings. Colwill and Rescorla give reasons for thinking that this procedural change might make the devaluation procedure more effective, leaving open the possibility that residual responding, when it does occur, is a consequence of an inadequacy in the devaluation procedure employed in those experiments.

But devaluation procedures, even when proven to be totally effective in reducing the rat's willingness to consume a reward, have sometimes been found to be quite ineffective in selectively suppressing the response that has previously produced that reward as the outcome. The experiment by Dickinson and Dawson (1987a), described above, in which the value of the reward was changed by means of a motivational shift, supplies one example; similar failures to produce an effect have also been found in experiments that devalue the reward by means of a pairing with Li (e.g., Balleine & Dickinson, 1991). But before concluding that the responding seen in these experiments is controlled by an S-R association, we must again consider the possibility that the particular procedures used may have failed to modify the value of the outcome (and thus failed to influence behavior based on an R-O association). Dickinson and Balleine (e.g., 1994; see also Chap. 12, this volume) have argued that revaluation of an (instrumental) outcome depends on a process that they call incentive learning: only when the animal has had the opportunity to experience the outcome under appropriate conditions (to try food pellets when thirsty rather than hungry, to sample a sucrose solution after it has been paired with Li) will the effective value of the outcome be changed. And indeed, Balleine and Dickinson (1991) have demonstrated just such an effect for the case of devaluation by Li-induced aversion (see also Dickinson & Dawson, 1988).

Dependence of the outcome-devaluation effect on appropriate reexposure to the

devalued outcome has not been a universal finding (e.g., Balleine & Dickinson, 1992; Rescorla, 1991a). But the source of this discrepancy is not our present concern. Rather, we need to ask if there are any cases of instrumental responding that show insensitivity to outcome devaluation even when every step has been taken (including reexposure to the devalued outcome) to ensure the effectiveness of the devaluation procedure. And the answer is that there are. An experiment by Adams (1982), which gave rats extended initial training on a continuous reinforcement schedule, found no effect of outcome devaluation on test responding, as did that by Dickinson, Nicholas, and Adams (1983), when initial training was given according to a variable interval schedule (the standard devaluation effect was seen when a ratio schedule was used in initial training). Dickinson's (e.g., 1989) interpretation of these experiments was that the training schedules they employed tended to minimize the extent to which the animal could experience a correlation between its responding and the occurrence of the outcome (on a variable interval schedule, for instance, rates of responding can vary over a wide range without producing variation in the rate of reinforcement). These conditions might be expected to work against the establishment of an R-O association and thus allow the S-R association to come to the fore. It should be acknowledged that other features of these experiments (in addition to the particular schedules used in training) must have contributed to their results (other experimenters, using somewhat different procedures, e.g., Colwill & Rescorla, 1985b, have found devaluation effects even in rats that are given extensive training on an interval schedule). However this may be, it is still legitimate to conclude that in some circumstances, even if these are rather special, it is possible to find evidence consistent with the assertion that instrumental training is capable of establishing an S-R association.

SIMPLE INHIBITORY CONDITIONING

In the standard Pavlovian *extinction* procedure, a pretrained CS is presented repeatedly in the absence of the US; in the instrumental case, the animal is allowed to perform the target response, but the previous outcome is no longer forthcoming. In both cases, the behavior established by initial conditioning disappears (the CS no longer evokes the CR; the probability of occurrence of the instrumental R falls toward zero). Since acquisition is referred to as excitatory conditioning, it seems only appropriate to refer to extinction as involving *inhibitory* conditioning—and this terminology has been widely adopted.

The issue to be addressed is what new associative structures are established by the extinction procedure and how might these structures explain the change in behavior that is observed. It will be immediately apparent, however, that structural considerations alone are unlikely to be sufficient to deal with extinction, and that some extension of our assumptions about the functioning of the system will be needed. So far we have made use of just two: Co-activation of a pair of nodes causes a link to form between them, and the existence of the link allows activity in one node to excite activity in the second. The fact that inhibitory learning occurs as a consequence of the presentation of just a single event seems, on the face of things, to present a challenge to the first of these assumptions. And the very use of the term *inhibitory* raises questions about the second—if acquisition deserves the label *excitatory* because it establishes a link that allows one node (e.g., the CS node) to excite activity in another (the US node), then the implication seems to be that the extinction procedure might have its effects because it establishes a link that has the opposite effect, in this example, inhibiting activity in the US node.

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Most recent attempts to explain inhibitory learning suppose both that it involves the formation of new associative links and that the conditions under which these are formed and the effects that they exert might differ from what holds for the excitatory case. But before discussing these theories, it will be worthwhile to establish that such elaboration is necessary. In particular, to accept that some new process is engaged by the extinction procedure raises the possibility that this, in itself, might be enough to explain the phenomenon, making it redundant to suppose that a new associative structure is also established. Evidence relevant to this notion is discussed next.

Process Accounts of Extinction

Extinction as Unlearning

We have supposed that the co-occurrence of activity in two nodes, produced by the near simultaneous presentation of the relevant events (CS and US, R and O), will strengthen the link between these nodes. What if presentation of the CS alone or the occurrence of the R without the O produces a weakening of the link? The outcome would be the extinction effect, without any need to suppose that a new associative structure is formed. With sufficient extinction trials, the original learning would be undone and the animal would be restored to the *status quo ante*. Unfortunately, given the elegant simplicity of this account, there is a good deal of evidence (some admittedly, suggestive rather than conclusive) to indicate that it is wrong.

Recovery of Extinguished Responding.

It has long been known (since, e.g., Pavlov, 1927) that a CR, extinguished by repeated, closely spaced presentations of the CS alone, will reappear if the CS is presented again after a substantial interval. More recent, and better

controlled, studies have confirmed the reliability of this Pavlovian *spontaneous recovery* effect (e.g., Rescorla, 1997a) and of its instrumental analogue (e.g., Rescorla, 1996a). In spontaneous recovery, the extinguished response returns after a retention interval. Other experimental manipulations can also generate recovery effects. The *renewal* effect involves manipulating the context in which training is given. If animals receive CS-US pairings in one experimental apparatus, followed by extinction trials in a discriminably different apparatus, the CR that has disappeared by the end of the extinction phase will return (be renewed) when the CS is again presented either in the original context or elsewhere (e.g., Bouton & Bolles, 1979a). In *reinstatement* (Rescorla & Heth, 1975; see also Bouton, 1984), animals given a “reminder” presentation of the US, after extinction has been completed, show recovery of the CR on a subsequent test session.

In none of these procedures can the experimental manipulation be expected to restore the strength of the original excitatory association, prompting the conclusion that this association must have been maintained during the extinction trials. What these observations do not allow us to conclude, however, is that the original link was maintained in full strength during extinction (i.e., that unlearning does not occur). An alternative interpretation is that the extinction procedure weakens the strength of the excitatory association to a point at which it falls below a threshold that must be surpassed if responding is to be evoked. Nonetheless, the original association may retain some strength that is able to show itself when the renewal or reinstatement procedure renders the test conditions more favorable. Perhaps, for example, the renewal effect reflects a summation of the weak CS-US association with the associative strength governed by the contextual cues of the original training context. Rather than discussing the

Table 1.1 Designs of Experiments by Rescorla (1993a, 1996b).

Training	Extinction	Retraining	Devaluation	Test
(a) Instrumental conditioning				
R1 → O1 & R2 → O2	R1– & R2–	R1 → O3 & R2 → O3	O1 → Li	R2 > R1
(b) Classical conditioning				
CS1 → US1 & CS2 → US2	CS1– & CS2–	CS1 → US3 & CS2 → US3	US1 → Li	CR2 > CR1

NOTE: R: instrumental response; CR: conditioned response; O: outcome in instrumental conditioning; US: unconditioned stimulus; CS: conditioned stimulus; Li: injection of lithium chloride.

experimental evidence directed at assessing the validity of this analysis (e.g., Bouton, 1991), we may turn to a different approach that attempts to demonstrate directly the permanence of excitatory associations.

The Persistence of Excitatory Associations. Table 1.1(a) presents a simplified version of the design of an experiment by Rescorla (1993a) investigating the effects of outcome devaluation on an extinguished instrumental response. In the first stage, two different responses were trained, each associated with a different reward. Both then underwent extinction. The final stages of the experiment assessed the effects of devaluing one of the outcomes used in original training (by associating it with Li). In order to see any effects of this procedure, it is necessary to reestablish some measure of responding. This was achieved by a retraining stage that immediately preceded outcome devaluation, in which both responses were reinforced by the delivery of a reward different from either of those used in the first stage. On tests, the animals readily performed R2 but rarely performed R1, the response associated in stage one with the outcome that had been devalued. Such a result could not have been obtained had information about the R1-O1 relationship been erased during the extinction phase. Rescorla's

experiment also included an assessment of the effect of outcome devaluation for a response that had not undergone extinction. The suppression of responding observed on the final test was no greater than that obtained for R1. According to this measure, therefore, the extinction procedure was quite without effect on the status or efficacy of the original R-O association.

Similarly, CS-US associations seem to be immune to the effects of extinction. Table 1.1(b) shows the design of a Pavlovian conditioning experiment (Rescorla, 1996b) analogous to that just described. Here the rats were first trained with two different CSs each associated with a different food US. Both CSs then underwent extinction until the CR (of approaching the site of food delivery) had disappeared. A retraining stage, using a different US, reestablished this response, allowing the effects of devaluation of one of the original USs to be assessed. The test showed a selective suppression of the CR to the CS that had been associated in the first stage of training with the now-devalued US. The size of this effect was comparable to that shown by animals treated equivalently but for the omission of the extinction stage, prompting the conclusion that the original CS-US association had been quite unaffected by the extinction treatment. Related experiments

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using a different procedure for assessing the strength of the original association (a transfer test procedure) have confirmed the reliability of this result for Pavlovian CSs (Delamater, 1996) and have demonstrated equivalent effects with stimuli trained as Sds (Rescorla, 1992).

Changes in Event Processing

The evidence discussed so far establishes that extinction is not to be explained as a process that simply dismantles the associative structure set up by excitatory training. This does not, however, force the conclusion that extinction must set up a new associative structure. It may simply mean that our first guess about the nature of the process engaged by extinction was wrong; instead, we should seek to explain the process as one that acts to prevent the intact excitatory link from fulfilling its normal function. Some possibilities emerge from the recovery effects described above.

One is suggested by the reinstatement effect. The interpretation originally offered by Rescorla and Heth (1975) was that the extinction procedure produces a change in the representation of the US, rendering it less easily excited by way of the CS-US link. According to this interpretation, the reminder trial is effective because it reestablishes the properties of the US node. There are several good reasons to reject this account. First, extinction will occur, albeit rather slowly, even when unsigned presentations of the US are scheduled to occur, interspersed among the nonreinforced CS trials (e.g., Rescorla & Skucy, 1969). Such presentations might be expected to maintain the status of the US node, and thus prevent extinction from occurring. Second, nonreinforcement of one CS does not necessarily produce extinction of a second (e.g., Bouton & King, 1983). If extinction occurs because of change in the US node, then both CSs should be affected equally. Third,

although early work seemed to suggest otherwise, it now seems clear that reminder trials are ineffective in producing reinstatement if they are given in a context that is different from that used for the other phases of training (Bouton & Bolles, 1979b). Why this might be the case will not be considered here; for present purposes it is enough to note that the theory under consideration has no reason to predict such an effect.

Although extinction cannot be explained in terms of a change in the properties of the US node, there remains the possibility that it reflects a change in the CS node. Pavlov (1927) himself appears to have entertained this possibility, attributing spontaneous recovery to the dissipation of a labile inhibitory process that suppressed the excitability of the CS node (an idea taken up and developed more recently by Robbins, 1990). If the CS is no longer able to activate its central representation, then no CR can be expected, even if the CS-US link remains intact. Something similar was proposed for the instrumental case by Hull (1943), who explained extinction by suggesting that every response evoked a state (akin to fatigue and labeled *reactive inhibition*) that made it more difficult to activate the response node on subsequent occasions. Spontaneous recovery was taken to reflect the dissipation of this state.

Neither of these proposals has stood up well to experimental testing. As Robbins (1990) has shown, spontaneous recovery can still be obtained when presentations of a different stimulus that evokes the same target response occur during the recovery interval. Hull's (1943) account supposes, however, that reactive inhibition (which is specific to the response) will continue to accumulate in these circumstances, thus predicting that spontaneous recovery will not occur. Evidence that extinction cannot be due to a loss of CS effectiveness comes from the procedure sometimes known as *counterconditioning*. Bouton

and Peck (1992) report a study in which rats were trained initially with a CS signaling a food US, followed by a second stage of training in which food deliveries were discontinued and replaced by the occurrence of a shock US. During this second stage, the CR typically supported by CS-food pairings disappeared; thus, at the behavioral level, extinction was observed to occur. Critically, however, during stage two the CS also acquired the ability to evoke a new CR indicative of the formation of a CS-shock association. This last observation implies that the CS must still have been effective in activating its central representation and thus permits rejection of the proposal that extinction of the food-related CR was a consequence of the loss of such effectiveness. This is not to assert that changes in CS effectiveness never occur—it is now widely accepted that repeated nonreinforced presentations of an event can reduce its ability to command some forms of processing (see Hall, 1991, for a review). But this effect is not the source of extinction: A fully familiar CS loses associability (becomes less good at entering into new associations), but its ability to evoke its CR still remains (Hall & Pearce, 1979; Pearce & Hall, 1980).

Structural Accounts of Extinction

Extinction does not erase the associative links formed during initial excitatory training; nor can it be explained in terms of nonassociative changes in the excitability or nature of the nodes connected by such links. Faced with these facts, theorists have turned to the alternative possibility of the extinction procedure engendering new associative learning—that it promotes the formation of a new associative structure that opposes or masks the effects of the original. Konorski was the first to clearly state this proposal (1948) and his formulation has set the agenda for most later discussions of the issue.

Konorski's Accounts

Konorski's (1948) approach to inhibitory Pavlovian conditioning was to treat it as being essentially parallel to the excitatory case, involving the formation of a new link between concurrently activated CS and US nodes. This link has different properties from those previously discussed—it allows presentation of the CS to inhibit activity in the US node (Konorski envisaged this as involving a raising of the threshold that the excitatory input must exceed to be effective). The pattern of coactivation that produces such a link must necessarily be assumed to be different in some way from that responsible for the formation of an excitatory link. Konorski suggested that the critical feature of the omission of the US was that it ensured that a high level of activity in the CS node would coincide with a rapid fall in (CS-generated) activity in the US node. These circumstances produce inhibitory learning, whereas the co-occurrence of increasing activity in both nodes (such as will happen when both CS and US are presented on the initial trials of acquisition) will produce excitatory learning. Wagner's (1981) model adopts much the same approach. It differs chiefly in its assumption that the activity induced in the US node by an excitatory CS (the A2 state) is different in nature from that produced by the US itself (the A1 state). Excitatory conditioning occurs when both nodes are in the A1 state; presenting the CS alone will ensure the co-occurrence of A1 activity in the CS node and A2 activity in the US node; this combination produces an inhibitory link, hence the extinction effect.

Konorski's (1948) scheme is shown in Figure 1.6a. During extinction training the inhibitory link is strengthened until the US threshold is sufficiently high that the excitatory link is incapable of generating any activity in the US node. Associative change will then stop and, of course, no CR will

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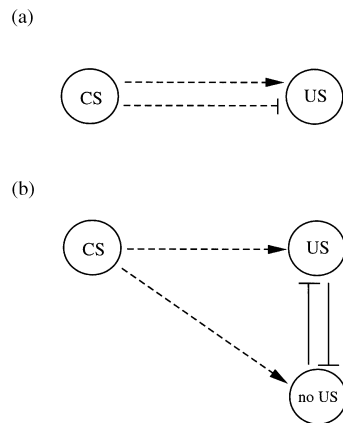


Figure 1.6 Alternative associative structures for inhibitory learning.

NOTE: (a) Konorski's 1948 theory. (b) Konorski's 1967 theory. A stopped link indicates that activity in one node can suppress activity in the target node; other conventions and abbreviations are as given for Figure 1.1.

be elicited. Adding the assumption that inhibitory links are inherently labile, or that first-learned associations are less susceptible to decay than later associations (or both of these), allows an explanation of at least some of the recovery phenomena described above.

In 1967 Konorski presented a radical extension and revision of his previous theorizing, one feature of which was the introduction of a conceptual nervous system more complex in its structure than any previously envisaged. In particular, it was suggested that representational nodes are frequently arranged in mutually antagonistic pairs—that, for example, the US node is connected by inhibitory links to a no-US node, and so on. The implication for extinction is the associative structure shown in Figure 1.6b. (In fact, the full picture is considerably more involved than this—since the US is assumed to have separable motivational and sensory properties, each of these should be shown separately with its own node and its own antinode.) As has of-

ten been noted (e.g., Rescorla, 1979b; but see also Mackintosh, 1983), the advantages bestowed by this new scheme seem to be only marginal—making the generation of inhibition in the US node a two-step process leaves the basic analysis unchanged. One possible advantage is that invoking a new structure makes it unnecessary to postulate a special inhibitory learning process—the conditions under which the CS–no-US link is formed are assumed to be the same (concurrent activation of the two nodes) as those that apply to standard excitatory conditioning. But this advantage is offset, to some extent, by the need to provide a precise specification of the conditions under which the no-US node is activated, a topic on which Konorski (1967) was less than forthcoming.

A further point is that the new structure makes it possible for the animal to have some knowledge about the nature of the event that had been omitted in inhibitory training. It is not obvious how a link that simply raises a US threshold could convey such information, but one that activates a node representing the absence of the sensory features of the US clearly has the potential to do so. The experimental evidence on this point is mixed. For example, Pearce, Montgomery, and Dickinson (1981) found that a CS that had signaled the omission of a shock US, otherwise applied to one eye of a rabbit, transferred its inhibitory properties perfectly well to a test in which shocks were applied to the other eye. This experiment thus supplied no evidence that the specific sensory properties of the omitted event had been learned about. By contrast, Kruse, Overmier, Konz, and Rokke (1983) found that a CS associated with the omission of a particular type of food would, when presented during instrumental responding, selectively reduce the vigor of a response that had previously been trained with that food-type as the outcome. Fortunately, we need not try to resolve this discrepancy here as Konorski's two

theories make essentially the same predictions about the inhibitory learning phenomena that are our present concern.

The structures presented in Figure 1.6 are concerned solely with Pavlovian conditioning, but they may also be relevant to the instrumental case. Konorski's (1967) account of excitatory instrumental conditioning assumed the existence of two associations, S-R and S-O, and thus the inhibitory process shown in the figure, which would act to oppose the excitatory S-O association, could contribute to extinction of an instrumental response. In addition, Konorski postulated the existence of what he termed "motor act inhibition", the idea being that the discriminative stimulus could form an excitatory association with a motor node (perhaps, by analogy with the no-US node, to be regarded as a "no-response" node) that was antagonistic to the node controlling the response being measured. Konorski did not acknowledge the role of the R-O association (as we now do), but it is a straightforward matter to extend his general account to deal with this. Just as the omission of the US that follows a previously reinforced CS is held to generate an inhibitory CS-US link, we may suppose that the omission of the usual outcome following performance of a given instrumental response might generate an inhibitory R-O link.

Conditioned Inhibition

Konorski's theory (to take the 1948 version) states that a CS that is active at a time when there is a fall in activity in the US node will form an inhibitory connection with the US node. In extinction, it is the CS itself that generates (by way of the preexisting excitatory link) the necessary state of activity in the US node, but there is no requirement that this be so for inhibition to be established. If some neutral stimulus is presented at the same time as a pretrained CS is undergoing extinction, this stimulus too should be able to form

an inhibitory link with the US node. Indeed, in a sense, such a stimulus should turn out to be an even more powerful inhibitor than the pretrained CS. The latter (referred to by Konorski as a secondary inhibitory stimulus) will be equipped both with excitatory and inhibitory links, the two matching each other in their effects on the US node. A stimulus introduced for the first time in the extinction phase (Konorski's primary inhibitory stimulus) will have only the inhibitory link.

The implication of this analysis is that (X+/AX-) discrimination training (in which animals receive reinforced trials when stimulus X is presented alone, but received extinction trials when X is presented in compound with some other stimulus, A) should be particularly effective in endowing A with inhibitory properties. Indeed, this training procedure, investigated by Pavlov (1927), was referred to by him as conditioned inhibition training. The conditioned inhibitor (A) showed its properties by suppressing the CR that X otherwise evoked. Figures 1.7a and 1.7b show how the associative structure postulated by Konorski's theories will generate such a result.

What Figure 1.7 also shows is a variety of other possibilities that might produce the same observed result. Stimulus A could, in principle, suppress the CR normally evoked by X by restricting the ability of X to excite its node (Figure 1.7c) or by directly inhibiting the CR itself (1.7d). A further possibility is that A might act on the link between X and the US (1.7e), gating the flow of activation from one node to the other. Confirmation of Konorski's account requires that these other possibilities be ruled out. The relevant evidence comes from an experiment by Rescorla and Holland (1977) in which the powers of a conditioned inhibitor were examined in a range of transfer tests. First they confirmed what had previously been shown in several other studies—that a shock-based conditioned inhibitor would suppress the CR not only of

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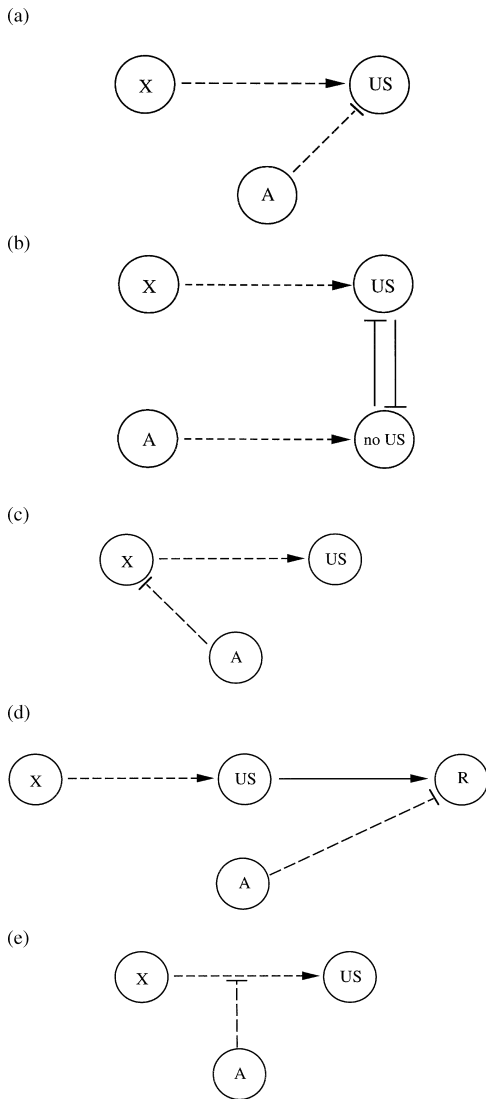


Figure 1.7 Alternative associative structures for conditioned inhibition.
 NOTE: X represents an excitatory CS, and A represents a conditioned inhibitor. Conventions and other abbreviations are as given for Figure 1.1. (a) and (b): Structures for Konorski’s proposal that the inhibitor acts on the US representation in terms of his 1948 theory (a) or his 1967 theory (b). (c) Structure in which the inhibitor acts on the excitatory CS. (d) Structure in which the inhibitor acts on the response node. (e) Structure in which the inhibitor acts on the link between CS and US.

stimulus X but also that normally evoked by a different excitatory CS separately trained as a signal for shock. The effect of the conditioned inhibitor is not specific to X, thus disconfirming, at least for this training preparation, options (c) and (e). They also showed that such a conditioned inhibitor was without effect on the CR evoked by an excitatory CS trained with a food US, adding support to the conclusion that the inhibition must operate either on the US node or on the CR itself (options (a) and (d)). In order to choose between the remaining alternatives, Rescorla and Holland made use of the fact that the CR evoked by an auditory CS signaling a food US is characteristically different from that evoked by a visual CS. They found that a conditioned inhibitor established for one of these CSs would transfer its power to the other, in spite of the difference in the form of the CR. The ability of a conditioned inhibitor to transfer across CSs and CRs but not across USs is what would be expected on the basis of the associative structure shown in Figure 1.7a.

Elaborations and Complications

Although consistent with most of the evidence cited so far, it remains to establish that the identification of extinction with US-specific inhibition can explain the full range of extinction phenomena. We will consider two lines of evidence that challenge the completeness of the account of extinction offered above. The first can be accommodated by an elaboration of the basic notion; the second requires a more radical revision of our assumptions about the nature of associations.

Sensory and Affective Properties of the US or Outcome. The experiments by Rescorla (1993a, 1996b), described above (see Table 1.1), appear to create some difficulties. These experiments showed, it will be recalled, that an extinguished response, reestablished by retraining with a different US

or instrumental outcome, still shows sensitivity to the effects of devaluing the original US or outcome. Why should this be, if the original US (or outcome) representation has been fully inhibited as a result of the extinction procedure? One obvious possibility (given the reality of spontaneous recovery) is that the inhibitory association may have decayed in some way during the retraining phase, allowing the originally trained excitatory association to make a contribution to test performance (a contribution that would be eliminated by the devaluation procedure). A problem for this interpretation is that Rescorla found the magnitude of the devaluation effect to be as great for extinguished associations as for associations that had not undergone extinction, making it necessary to assume (what seems improbable) that the loss of inhibition in the former case had been total.

An explanation emerges, however, if we recall (what was discussed in our consideration of excitatory conditioning) that a US (or outcome) is likely to be represented by at least two nodes, one corresponding to its affective and another to its sensory properties. Initial training will establish excitatory associations with both these nodes (and will also, if it is not in existence already, establish a link between the sensory and affective properties of the US). The situation for the instrumental case is shown in Figure 1.8a. Now the omission of the expected outcome at the start of extinction produces a new and clearly salient affective state: A rat that presses the lever and fails to obtain the expected food pellet shows a characteristic set of vigorous emotional responses that have been taken to index a state of frustration. It is reasonable to assume that these responses or the state that produces them will be able to enter into associations. The absence of the specific sensory properties of the food pellet will be a much less salient event and is less likely to produce new learning. The consequence will be an associative structure of the

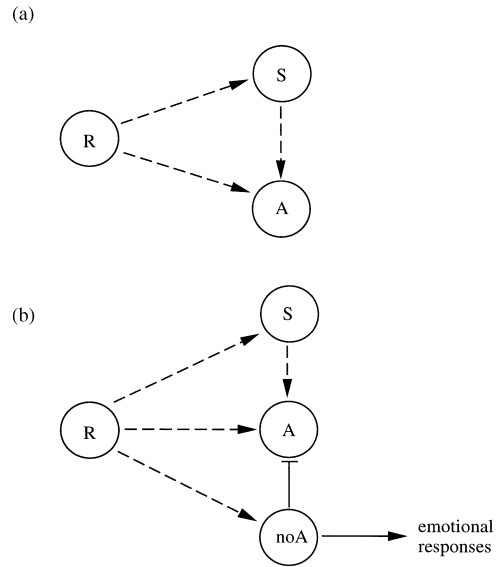


Figure 1.8 Associative structures for instrumental conditioning with separate nodes for affective (A) and sensory (S) properties of the outcome. NOTE: (a) Structure produced by excitatory conditioning. (b) Structure produced by extinction employing the notion that the absence of affective properties (no A) is represented by its own node. Conventions are as given for Figure 1.1.

sort shown in Figure 1.8b. (The figure postulates a node of the sort proposed in Konorski's later, 1967, theory, although other formulations are possible—Rescorla, 2001, himself, suggests that the relevant association may be directly with the emotional responses themselves). The new learning produced by extinction could therefore inhibit the motivational state necessary for responding, although the animal's knowledge of the relationship between its response and certain sensory events and of the relationship between the latter and a positive affective state might remain more or less intact. Retraining with a different outcome of the same affective value as the original will restore responding because it restores the ability of the response to activate the positive emotional state. A devaluation procedure that associates the sensory properties of the

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outcome used in original training with an aversive consequence will then be able to act upon this positive state and produce a suppression of responding—the result obtained in the experiment by Rescorla (1993a).

Although seemingly complex, this account is no more than an elaboration of the basic principles that we have accepted so far. Indeed Rescorla's (2001) endorsement of the proposal that extinction involves new excitatory learning about the events that actually occur as a consequence of omission of the outcome (or US) has the advantage (shared with Konorski's later theory) of not requiring us to postulate a special inhibitory learning process. To this extent, it can be seen as a simplification. The next line of evidence to be considered, however, seems to require the introduction of a new associative principle.

Response-Specific Inhibition. The essence of the conclusion derived from the work of Rescorla and Holland (1977; see Figure 1.7) was that extinction operates on the US representation, not on the system responsible for generating the response. But a recent set of experiments by Rescorla himself has produced results that challenge this idea. These experiments, using instrumental training procedures for the most part, have evaluated the properties acquired by a stimulus in the presence of which extinction has occurred (e.g., Rescorla, 1993b, 1997b). The design of one such experiment (Rescorla, 1993b, Experiment 4) is shown in Table 1.2. Rats

Table 1.2 Design of Experiment by Rescorla (1993b).

Training	Extinction	Retraining	Test
R1 → O & R2 → O	S1: R1– & S2: R2–	R1 → O & R2 → O	S1: R2 > R1 & S2: R1 > R2

NOTE: R: instrumental response; O: outcome; S: discriminative stimulus.

were trained initially to make two different responses, each of which generated a food pellet outcome; both then underwent extinction, one in the presence of a light, the other in the presence of a noise. A retraining phase reestablished some measure of responding, allowing the properties acquired by these stimuli to be assessed in a final test. Both showed evidence of having acquired inhibitory power, but their effects were specific to the response with which they had been trained: S1 (see Table 1.2) had no effect on the rate at which R2 occurred but suppressed performance of R1; S2 suppressed R2 but had no effect on R1.

The account of extinction that we have been developing to this point predicts no such response-specificity. As shown in Figure 1.9a, by the end of extinction, both stimuli (and both responses) should have acquired the power to inhibit the outcome representation (or, as shown, to excite an antagonistic no-outcome representation). Reestablishing the response-outcome associations through further reinforced training would permit the association governed by a stimulus to influence behavior by inhibiting activity in the outcome node, but since the outcome is common to both responses, both should be suppressed equally.

The most straightforward interpretation of this experimental result appears to be that the extinction phase of Rescorla's (1993b) experiment establishes an associative structure of the sort shown in Figure 1.9b, in which the stimulus comes to exert an inhibitory influence on the response node itself. But to adopt this interpretation creates as many problems as it solves. Chiefly, it now becomes necessary to specify what it is about the extinction procedure that causes such inhibitory links to form. So far we have assumed that the coactivation of a response node and a stimulus node will establish an excitatory link—and just such a coactivation is arranged in the extinction phase of Rescorla's (1993b)

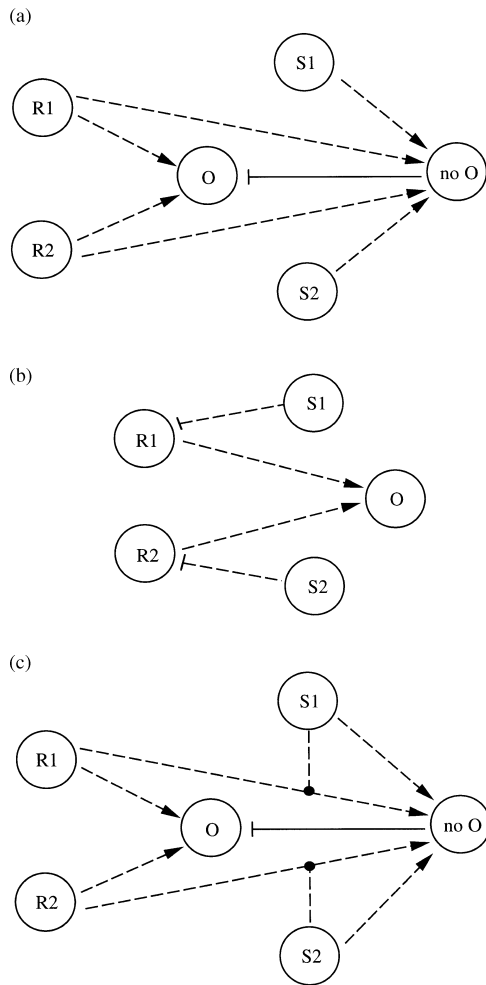


Figure 1.9 Possible associative structures generated by the training procedures outlined in Table 1.2.

NOTE: S1 and S2 represent two different discriminative stimuli in the presence of which two different responses, R1 and R2, have undergone extinction. No O represents the omission of a given outcome (O). In (c) a link that ends in a filled circle is assumed to be able to modulate activity in the associative link with which it makes contact. Other conventions are as given for Figure 1.1.

experiment. The advantage of the structure shown in Figure 1.9a is that it accords perfectly well with our established principles, assuming that in extinction, as in acquisition, an orthodox association is formed between

the response and what actually accompanies it. Figure 1.9c shows one way in which this advantage can be maintained while still providing an explanation for response-specificity in extinction. It supposes that the training given to the stimuli allows their nodes to form links, not (or not only) with the other nodes that are active when they are presented, but with other associations. Specifically the figure shows how each stimulus may come to activate the particular response-no outcome association that was formed in its presence. Such a stimulus can be expected to have a general effect on responding (the direct link with the no outcome node will still be formed), but in addition it will have a specific effect by selectively activating just one of the response-no outcome links.

This interpretation is one example of what has been referred to as a “hierarchical” account of conditioning in which higher-order associations operate on and determine the functioning of lower-order, simple associations of the sort that have dominated our discussion so far. To adopt this interpretation solves the immediate explanatory problem but raises a range of further questions. We have a clear rule specifying when one node will form a link with another, but what determines when a node will form a link with an association between two other nodes? (The experimental analysis of conditioned inhibition by Rescorla and Holland, 1977, for example, provided no support for the hierarchical structure depicted in Figure 1.7e.) We have a well formed idea of how activity in one node can generate activity in another with which it is linked, but by what process can a node influence the properties of an association? And, more basically, is there any independent evidence that would persuade us to take seriously what is, at this stage, merely an ad hoc assumption devised to explain a specific set of experimental results? These issues form the focus of the next section of the chapter.

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COMPLEX CONDITIONING

Early in the study of instrumental learning it was demonstrated that responding can be brought under stimulus control: If a lever press results in a food pellet only when some external stimulus is presented, a rat will come to confine its responding to periods when the stimulus (the Sd) is present. Similarly, when food is available only in the absence of a given stimulus (known as an S-delta) the rat will learn to refrain from responding in the presence of the stimulus. Skinner (1938), who first investigated these effects in any detail, was insistent that the role of such discriminative stimuli was not to elicit (or suppress) the response directly; rather the stimuli were said to “set the occasion” on which the response would or would not be reinforced.

Parallel phenomena can be demonstrated in Pavlovian conditioning. In the procedure sometimes known as *feature positive* training, a CS (X) is paired with the US only when it is preceded or accompanied by some other stimulus (the so-called feature stimulus, A; the terminology reflects the fact that a distinctive element or feature is present on one of the two trial types, in this case on the reinforced, positive, trial). Animals given a mixture of AX+/X- trials come to show the CR to X only on trials when the feature is also present. In the *feature negative* case (AX-/X+), responding comes to be restricted to those trials on which the CS occurs in the absence of the feature. We have already met a version of this latter procedure in our discussion of conditioned inhibition, and it has been the subject of investigation since it was first introduced by Pavlov himself. Interest in the feature positive case has developed only in recent years (initiated by the pioneering study of Ross & Holland, 1981). Holland (e.g., 1983) made the parallel with the instrumental case quite explicit by labeling these Pavlovian procedures as occasion-setting and by re-

ferring to the feature stimulus as an occasion setter.

What characterizes these procedures is that they all involve a conditional relationship. In each, the response or target CS is sometimes followed by an outcome and sometimes not; what occurs is conditional on whether or not the discriminative stimulus or feature stimulus (the occasion setter) has also been presented. What makes them important is the suspicion (held as an article of faith by Skinner) that it may not be possible to explain them in terms of the associative principles and structures that have proved adequate for simple conditioning. The first part of this section of the chapter lays out the evidence that appears to confirm this suspicion. Later parts discuss those theories that have introduced new associative structures, new processes, or both, in order to explain complex, conditional conditioning.

The Role of Simple Associative Mechanisms

Instrumental Conditioning

The procedures used in rewarded instrumental conditioning permit the formation of simple excitatory associations between the Sd and the outcome and between the Sd and the response. In an earlier section of this chapter, we considered the possibility that the Sd might exert its effects by way of its association with the outcome; according to classical two-process theory (although other interpretations are possible; see Trapold & Overmier, 1972), such an association generates the motivational state that is necessary for the instrumental association to be expressed in behavior. But we also found reasons for doubting the adequacy of this interpretation. In particular, it was demonstrated that CSs and Sds are not interchangeable in the way that this account requires. And given the evidence (also discussed earlier in

Table 1.3 Design of Experiment by Colwill and Rescorla (1990b).

Training	Devaluation	Test
R1 → O1		
S1: &		
R2 → O2		S1: R2 > R
	O1 → Li	
R1 → O2		S2: R1 > R2
S2: &		
R2 → O1		

NOTE: R: instrumental response; O: outcome; S: discriminative stimulus; Li: injection of lithium chloride.

the chapter) supporting the view that S-R associations play no more than a minor role in generating instrumental responding, it would seem unwise to rely on this mechanism as an explanation of stimulus control.

In fact there is direct experimental evidence to show that Sds can exert control by means that are independent of any Sd-R or Sd-O associations that may be formed. An example comes from a study by Colwill and Rescorla (1990b), the design of which is summarized in Table 1.3. In a first stage of training, rats learned to perform two different responses for two different outcomes. Which response produced which outcome depended on which of two Sds was present. Such training could, potentially, establish direct links between each Sd and both responses and between each Sd and both outcomes. In the next stage of training, pairing with Li was used to devalue one of the outcomes. When the Sds were presented again in the test phase, the rats showed an unwillingness to perform the response that had previously produced the now-devalued outcome in the presence of that Sd. Simple associations cannot explain this result: The devaluation procedure should be without effect on S-R links; devaluing the outcome of an S-S link should have equivalent detrimental effects on both responses. Clearly what is critical is the specific combination of response and outcome; we may conclude that

what is learned about an Sd includes some information about the relationship between the response and the outcome that have occurred together in its presence.

What is true for Sds also hold for S-deltas. When responding is reinforced in the presence of stimulus X but not in the presence of the compound AX, it is possible that stimulus A (the S-delta) will acquire the properties of a Pavlovian conditioned inhibitor. The ability of A to suppress the animal's tendency to perform the target response might thus be attributed, in principle, to a capacity to inhibit the excitation of the outcome representation that the Sd, X, would otherwise evoke. Depending, as it does, on the questionable notion that the Sd works by way of a direct association with the outcome, such an interpretation may immediately be seen to be implausible. Experimental studies paralleling those described for the case of the Sd confirm this conclusion. The lack of interchangeability between an S-delta and a CS trained as a conditioned inhibitor has been demonstrated by Bonardi (1988). Two groups of rats were trained on the AX-/X+ task; for one group, responding was required for food to be delivered in the presence of X, that is, A was trained as an S-delta; for the other group, the animal's responses were irrelevant. The training given to the latter group might be expected to establish stimulus A as a Pavlovian conditioned inhibitor, and this was confirmed in a subsequent test in which A was paired with a US. The retardation of excitatory conditioning that was observed with this procedure is what would be expected of a CS having inhibitory properties. Significantly, however, inhibition was not evident in this test for the animals trained on the instrumental version of the initial discrimination. A further test examined the effects of presenting stimulus A while the animals were responding to the presentation of a separately trained Sd. On this test, the stimulus trained as an S-delta tended

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Table 1.4 Design of Experiment by Bonardi and Hall (1994).

Stage 1	Stage 2	Test
X: R1 → O1 & AX: R1– & Y: R2 → O2 & AY: R2–	Z: R1 → O1 Z: R1 → O2	AZ: lower response rate AZ: higher response rate

NOTE: R: instrumental response; O: outcome; A, X, Y, and Z: different discriminative stimuli.

to suppress responding whereas the Pavlovian inhibitor did not. Evidently, an S-delta will not function as a conditioned inhibitor, nor will a conditioned inhibitor function as an S-delta.

Evidence that an S-delta can produce effects that are specific to the combination of response and outcome with which it has been trained comes from an experiment by Bonardi and Hall (1994). Table 1.4 presents a simplified version of the experimental design. In the first stage of training, rats learned to perform one response for a given outcome (a particular type of food) in the presence of one Sd and a different response for a different outcome in the presence of another. Responding was not rewarded when either of these Sds was presented in compound with the S-delta, stimulus A. In the second stage of training, a new Sd was established; for half the animals, this signaled one of the response-outcome relationships that had been used in stage one; for the remainder, the relationship was switched so that the response now produced the other type of food as its outcome. A final test showed that the S-delta was more effective in suppressing the responding governed by this new Sd in the former group than in the latter. In the first stage of training, stimulus A had the opportunity to become associated with the extinction of both responses and the omission of both types of food. But if this was all that

the animals learned about A, the way in which the responses and reinforcers are combined on the transfer test should be immaterial. The specificity of the effect obtained on the test suggests, rather, that the S-delta operates on the entire response-outcome association. This conclusion accords precisely with that drawn above on the basis of Rescorla's (1993b) study of simple extinction (see Figure 1.9).

The evidence discussed in this section confirms the suggestion that discriminative stimuli do not act (solely) by way of the simple associative properties they may acquire. An understanding of how they do act (whether by way of the hierarchical structure shown in Figure 1.9c, or in some other way) is best achieved in the light of information gained from the study of Pavlovian conditional discrimination tasks. As a preliminary, therefore, it is necessary to establish that these too cannot be explained in simple associative terms.

Feature Positive Discriminations

That animals can learn to respond to a reinforced compound stimulus (AX+) and not to presentations of a nonreinforced element (X–) requires no special assumptions. Standard accounts of the principles that govern the growth of associative strength (e.g., Rescorla & Wagner, 1972) predict that the more valid predictor, A, will readily gain strength whereas X will gain much less strength, eventually being rendered associatively neutral. The same patterns of associative strength might also be predicted for the case in which when a serial compound is used (i.e., when A precedes X, to be symbolized as A → X+), a procedure commonly used in studies of occasion setting (e.g., Holland, 1985b; Rescorla, 1985). Thus, it is of interest that animals trained with the serial procedure can develop a discrimination in which they come to respond to the supposedly weak or neutral X element on those trials in which it follows A. This result has been obtained

when A itself generates no obvious CR (e.g., Rescorla, 1985) and when the CR to A is different from that generated by the stimulus used as X (e.g., Ross & Holland, 1981). It thus seems unlikely that the response to X, when it occurs, could simply reflect a carry-over of the responding initiated by stimulus A. Rather, these results seem to suggest that a direct X-US association is indeed formed with this training procedure and that the role of A is to establish the conditions that allow this association to show in behavior.

Wagner and Brandon (1989) have developed an account of the role of stimulus A that requires no new principles additional to those used in the explanation of simple conditioning. We have already discussed the notion that in some circumstances CS-US pairings are likely to establish an association primarily between the CS and the affective properties of the US. Such a CS may not elicit a discrete CR, but it will evoke a motivational state (referred to by Konorski, 1967, as a *preparatory* CR), the presence of which will enhance the vigor of a discrete CR (Konorski's *consummatory* CR) controlled by some other CS. Wagner and Brandon argue that the specific temporal arrangement employed in many studies of serial ($A \rightarrow X+$) feature positive training are such that stimulus A is likely to become associated with just the affective properties of the US, whereas X will become associated with the specific sensory properties of the US. Although A will not itself be capable of evoking the consummatory CR, it will supply the necessary motivational background that allows X to do so.

There is experimental evidence to confirm the validity of this analysis and to show that it operates in certain training preparations (see, e.g., Bombace, Brandon, & Wagner, 1991; Brandon & Wagner, 1991). But there are also good reasons for thinking that it cannot be the sole source of the occasion-setting effect. We shall briefly consider three

of these. First, there is considerable evidence (to be discussed in more detail below) showing that the effects of A are, to some extent, specific to the CS with which it has been trained. A separately trained CS that has been subject to the same schedule of reinforcement as cue X should, in principle, be just as susceptible to the effects of the emotional state engendered by A as the original cue. But although responding to the test CS may be boosted to some degree, the size of the effect is much less than that obtained with the original CS (e.g., Brandon & Wagner, 1991). Second, if the source of A's powers lies in its direct Pavlovian association with (the affective aspects of) the US, then a separately trained excitatory CS should have similar response-enhancing powers when presented before the target stimulus. Adequate tests of this proposition are hard to come by, as it proved difficult to arrange a training procedure that ensures that the simple CS and the stimulus trained as an occasion setter are exactly matched in their associative strength. With this caveat in mind, we may note that experiments that have investigated the matter have usually found that a simple excitatory CS is an inadequate substitute for a true occasion setter (e.g., Rescorla, 1985; Rescorla, 1987; Ross & Holland, 1981). Finally, if A's occasion-setting power depends on its ability to function as an excitatory CS, then extinction of A should eliminate this power. Although Holland (1989a) found just this result for rats trained with a simultaneous compound stimulus ($AX+/X-$), studies of the effect of nonreinforcement of A after serial feature positive training ($A \rightarrow X+/X-$) have routinely found that A's powers are unaffected (e.g., Rescorla, 1986), or even enhanced (Holland, 1989a).

Feature Negative Discriminations

In our discussion of conditioned inhibition we considered the procedure in which an animal

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learns a discrimination between a reinforced element and a nonreinforced simultaneous compound (AX−/X+). Experimental analysis (Rescorla & Holland, 1977) led to the conclusion that the absence of responding to the compound reflected the ability of A to inhibit activation of the US node (see Figure 1.7a,b). Experiments analogous to those just described for the feature positive case give reason to doubt that this simple inhibitory mechanism can supply an explanation for all examples of feature negative discrimination, in particular, for those using a serial (A → X−/X+) training procedure.

Since the central observation is that responding to X is suppressed, the form of the CR can yield no information in this case. There are, however, very many studies looking at the extent to which A's powers will transfer to another separately trained CS. These will be discussed in more detail below; for the time being, it is sufficient to note that transfer may fail to occur although the same US has been involved in training both CSs (e.g., Holland, 1989b; interestingly, this study also included a demonstration of successful transfer in animals trained initially with simultaneous rather than a serial compound AX stimulus). The absence of transfer suggests that the serially trained A stimulus had not acquired the ability to inhibit the US representation. Further evidence to support this conclusion comes from studies showing that procedures designed to eliminate any direct inhibition that A may have acquired do not remove its occasion setting properties. Holland (1989b; see also Holland, 1984) gave rats reinforced trials with A after initial training on the serial feature negative discrimination. That A came to evoke the CR was evidence that any inhibitory properties had been effectively counteracted by this procedure. Nonetheless, the A stimulus still proved capable of suppressing responding to X on a subsequent test. (Again, different effects were obtained

after initial training with a simultaneous compound; here counterconditioning of the feature element abolished its ability to suppress the responding governed by the target.) Even more striking evidence of a dissociation between the simple associative properties of a feature stimulus and that feature's occasion-setting power comes from a study by Rescorla (1991b). In this experiment the subjects (pigeons) received reinforcement of the feature stimulus while concurrently learning a serial feature negative task (that is, they received A+/A → X−/X+ training). Not only did stimulus A suppress responding to X, it appeared to do so even more effectively than one that had not received such reinforced training.

Relationship between Occasion Setting and Simple Association Formation

A further reason for thinking that occasion setters do not exert their effects by way of any simple excitatory or inhibitory associations they may control comes from the observation that occasion setting effects are best obtained in circumstances that are likely to restrict the development of such associations.

As we have just noted, several of Holland's experiments allow a comparison of the effects of training with serial rather than simultaneous compound stimuli. These have found that the feature stimulus acquires occasion-setting properties more readily when the serial arrangement is used—an arrangement that would work against the formation of a strong association between the feature stimulus and the (temporally remote) outcome of the trial. Ross and Holland (1981; see also Holland, 1986) examined this issue in a study of serial feature positive training in which the interval between the feature stimulus and the reinforced CS was manipulated. As might be expected, the ability of the feature to evoke an overt CR declined somewhat as this interval (and thus the delay of reinforcement) was increased. Its ability to act as an occasion

setter (to potentiate the elicitation of the CR by the target) showed no such effect, growing steadily more powerful as the interval was increased.

This is not to say that the serial procedure will always produce occasion setting and that the simultaneous procedure can never do so. An experiment by Rescorla (1989), looking at feature negative discrimination in pigeons, found the inhibitory properties acquired by the feature to be much the same after serial as after simultaneous training; conversely, Holland (1989c) found evidence for occasion setting in rats trained with a simultaneous feature positive procedure. It should be noted, however, that Rescorla used a training procedure in which presentation of the feature immediately preceded that of a relatively brief target CS—an arrangement likely to foster the development of a direct association between the feature and the outcome of the trial. Holland's experiment made use of a very salient target stimulus, and it is well known (from studies of the phenomenon of overshadowing) that the presence of such an element in a simultaneous compound will restrict the acquisition of associative strength by its less salient companion. The critical factor in producing occasion setting appears to be not so much that the compound is serial rather than simultaneous; instead, it is that the training procedure is one that does not allow the acquisition of direct associations by the feature (but see Holland, 1992, for a full discussion of other possible interpretations).

We may conclude that, although simple associations involving the feature stimulus and the US node may support the learning of some feature positive and feature negative discriminations, another mechanism comes into play when the circumstances are such that the relevant simple associations are unlikely to be formed. Consideration of why this should be so gives a hint as to what the other mechanism might be. When animals are trained

on a simultaneous, AX+/X− feature positive discrimination, standard associative principles (e.g., Rescorla & Wagner, 1972) predict that A, being better correlated with reinforcement than X, should develop a particularly strong association with the US and do so at the expense of X. Similarly, for the AX−/X+ task, A, being uniquely correlated with nonreinforcement, will gain the lion's share of inhibitory strength. Only when the conditions are such that A is unable to gain much strength will X be able to do so. The critical feature of the experimental procedures described above may be not so much that they limit the acquisition of associative strength by stimulus A as that they allow the target CS X to acquire strength. The implication is that the feature may be able to acquire (or exhibit) occasion-setting properties only when its target stimulus has a reasonable amount of associative strength. This conclusion accords with the proposal that occasion setters work by *modulating* the effectiveness of standard excitatory or inhibitory associations. We examine this proposal in more detail next.

Modulatory Accounts of Occasion Setting

Associative Structures

The modulatory interpretation of occasion setting treats the target stimulus X as a standard CS that is subjected to a mixture of reinforced and nonreinforced trials. According to the analysis developed in previous sections of this chapter, this training will establish both excitatory and inhibitory links between the X node and that representing the US (see Figure 1.10). The exact schedule of reinforcement employed will determine the balance between the excitatory and inhibitory effects. We must assume that in the feature negative case the excitatory process predominates (X is capable of evoking the CR when A is not present); in the feature positive case (where

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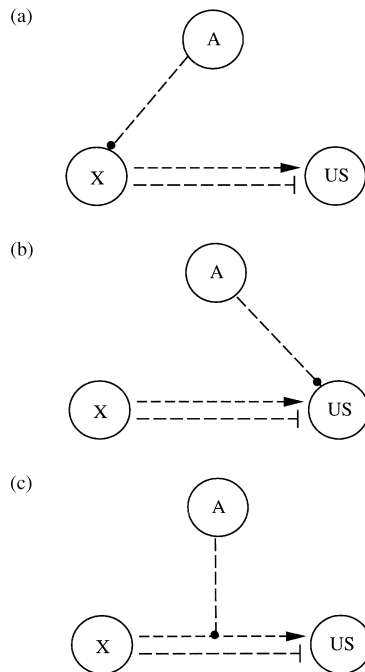


Figure 1.10 Possible associative structures according to modulatory accounts of occasion setting.

NOTE: A represents an occasion setter, and X represents a CS. The link ending in the filled circle is assumed to be able to modulate activity in the node or link with which it makes contact. Other conventions are as given for Figure 1.1. In (c) the modulation is shown as acting on the excitatory link between CS and US; it may also act on the inhibitory link or on both links.

X alone will not evoke the CR), we must assume that, even if the net effect of the CS is excitatory, the amount of excitation generated is not enough to pass the threshold necessary for the evocation of responding. Modulatory theories assume that occasion-setting training endows the feature stimulus with ability to modulate the effectiveness of one or other (or both) of these orthodox CS-US associations. In the feature positive case, it will be the excitatory effect that is enhanced, or the inhibitory one suppressed, or both; in the feature negative case, the reverse pattern must be assumed to operate.

Having adopted this general framework, it becomes necessary to specify where in the basic CS-US structure the occasion setter operates and exactly how it exerts its modulatory effect. Figure 1.10 shows three possibilities. All assume—in line with the theoretical position that has proved satisfactory so far—that the node representing the feature stimulus becomes linked to some other structure: to the CS node (Figure 1.10a), to the US node (Figure 1.10b), or to one or another of the associative links between the nodes (Figure 1.10c). The structures shown in the figure may seem simply to be elaborations of those already described for simple excitatory and inhibitory conditioning; it should be noted, however, that to adopt any of these also requires us to postulate the operation of a new process. The link running from the A node cannot have its effects (as, for example, an orthodox excitatory link is supposed to do) merely by engendering activity in a target node. This is most obvious for the structure shown in Figure 1.10c where the A node is connected not to another node but to the associative link between CS and US; but it also applies to the other two possibilities illustrated. With respect to the structure shown in 1.10b, we have already discussed evidence indicating that occasion setting is best obtained in circumstances that preclude the formation of a strong direct association between the feature and the US representation. With respect to that shown in Figure 1.10a, there is no reason to suppose that occasion-setting training will fail to establish a direct excitatory association between A and X, but there are good reasons to think that this link is not responsible for the occasion-setting effect (at least in the feature positive case). A direct association of this sort might allow stimulus A to “prime” excitatory activity in the X node prior to the presentation of X itself. But the evidence currently available suggests that the effect of such priming is to reduce, rather than enhance, the ability of the CS to

excite activity in its node (Wagner, 1976; Hall & Mondragón, 1998). The effect would be the reverse of that observed in feature positive discrimination training. The link from A to X depicted in Figure 1.10a must have its occasion-setting effect in some other way.

One possibility is that the link enables activation of the A node to change the threshold for activation of the X node. Lowering the threshold would enhance the effectiveness of the CS and thus increase the likelihood that any low level of excitation it may control would activate the US node (the feature positive result); raising the threshold would make the CS less likely to activate the US (the feature negative result). A similar process might operate within the structure shown in Figure 1.10b: the feature positive effect would be obtained if A reduced the threshold for activation of the US node, and the feature negative result if A raised the threshold. (This is just the analysis of occasion setting developed by, e.g., Rescorla, 1985.) The notion that a link might be able to change the threshold associated with a node will already be familiar from our discussion of inhibitory learning (although the evidence, cited above, that a serially trained negative feature does not appear to act as a conditioned inhibitor raises doubts about its applicability in this particular case). The third possible structure (Figure 1.10c) requires a more radical theoretical step. Here the link from A is supposed to operate not on another node but on the associative link itself. Presumably, its effect must be to promote the passage of excitation (or hinder that of inhibition) in the feature positive case; to promote inhibition (or hinder excitation) in the feature negative case. This view of occasion setting, or a version of it, has been advanced by Holland (e.g., 1985b).

Clearly, to adopt any of the interpretations of occasion setting depicted in Figure 1.10 raises a number of questions about the processes implied by the structures they postu-

late. Our concern here, however, is to determine which, if any, of these structures is established by the occasion-setting procedure. Attempts to do this have made use of tests that examine the effects exerted by an occasion setter on a CS-US association other than that with which it was originally trained. Such transfer tests, it is suggested, can allow us to determine the target of occasion setter action.

Transfer Tests in Occasion Setting

If the feature stimulus in occasion setting operates by way of an effect on the CS node (as in Figure 1.10a) then this stimulus should be without effect on the responding controlled by a separately trained CS-US association. The alternative view (that the feature operates on the US node; Figure 1.10b) predicts that transfer will occur to a new CS, provided that the US remains the same. Experiments testing these seemingly simple predictions have been carried out on many occasions (see Swartzentruber, 1995, for a review) and have produced a varied pattern of results that defies any simple explanation. If we consider just the feature positive case, it is possible to find studies in which transfer to another CS appears to be complete (e.g., Rescorla, 1985), in which it fails to occur (e.g., Holland, 1986), and, quite commonly, studies in which the feature is able to boost the responding governed by the test CS to some degree, but to a lesser extent than is seen when the occasion setter is presented with its original CS (again, see Rescorla, 1985; Holland, 1986).

A close inspection of the details of the various experiments might help resolve these discrepancies (in particular, there is reason to think that the exact training history of the CS used in the transfer test may be a critical variable). But whatever the outcome of such a survey, it is important to appreciate that the result would not necessarily be theoretically decisive. Although the structure shown

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in Figure 1.10a seems to demand that occasion setters be target-specific, this is only so if we neglect the possibility that generalization is likely to occur between the test CS and that originally trained. To the extent that the animal fails to discriminate between the two CSs, transfer can be expected to occur. Similarly, a failure to find perfect transfer does not rule out the US-specific model of Figure 1.10b. Presenting the feature prior to the test CS could change the way in which the latter is perceived (that is, generalization decrement could occur)—the consequent disruption of conditioned responding would look like incomplete transfer even though the feature was fully capable of acting on the US representation.

An experiment by Bonardi (1996) goes some way toward resolving these issues. Pigeons were trained concurrently with two occasion-setting stimuli (A and B) and two CSs (X and Y) under the following contingencies, $A \rightarrow X+/X-$ and $B \rightarrow Y+/Y-$ (that is, X was reinforced when preceded by A but not when presented alone; similarly for Y and B). The subjects came to respond to the cues X and Y only when they were preceded by their occasion setters. They then received test trials in which each CS was preceded by the “wrong” occasion setter (i.e., $A \rightarrow Y$ and $B \rightarrow X$). The result was partial transfer—the pigeons responded to the CSs under these conditions but did so less vigorously than when the CSs were preceded by the “right” occasion setters. As we have seen, the view that the feature operates by way of the US representation explains this failure to obtain complete transfer by appealing to the effects of generalization decrement. In order to test this suggestion, we need some independent measure of the extent to which experiencing a novel combination of occasion setter and CS on the test does indeed produce generalization decrement. To achieve this, Bonardi included a condition in which the animals received ini-

tial training with cues (A and B) associated with continuously reinforced CSs (effectively, $A- \rightarrow X+/X+/B- \rightarrow Y+/Y+$). Such training would not be expected to establish occasion setting, but the novel test combinations, $A \rightarrow Y$ and $B \rightarrow X$, might still be expected to produce generalization decrement. No such effect was seen—after this form of training, test responding was as vigorous to the novel combinations as to those used in initial training. We may conclude that the decrement seen on the transfer test after occasion-setting training is not a product of generalization decrement; rather it indicates that the control exerted by the feature shows some degree of specificity to the target CS with which it was trained.

To demonstrate CS-specificity in occasion setting is only a first step, for this result is predicted not only by the structure shown in Figure 1.10a, but also by that in Figure 1.10c in which the feature acts on the CS-US combination. These accounts differ, however, in that the latter predicts that occasion setting should also show US-specificity—transfer should fail to occur when the test involves a separately trained association between the original CS and some new US. Such a test is technically difficult to arrange and, it should be noted, the result could still be ambiguous. A demonstration that occasion setting shows specificity both to the CS and US used in original training would not require us to accept the structure shown in Figure 1.10c. This pattern of result could be accommodated by supposing that the feature acts independently on both the CS and US representation (i.e., that the structures shown in Figures 1.10a and 1.10b are both correct). Confirmation of the accuracy of the structure of Figure 1.10c requires evidence that the occasion setter’s action is specific to the association—to the *combination* of CS and US.

Table 1.5 shows a simplified version of the design of an experiment (Bonardi &

Table 1.5 Design of Experiment by Bonardi and Ward-Robinson (2001).

Stage 1	Stage 2	Test
A → X → f1/X-	A → XS → f1	S: lower response rate
A → Y → f2/Y-	A → XD → f2	
B → Y → f1/Y-	A → YS → f2	D: higher response rate
B → X → f2/X-	A → YD → f1	

NOTE: A, B, X, Y, S, and D: Pavlovian conditioned stimuli; f1 and f2: different types of food.

Ward-Robinson, 2001) intended to supply the relevant evidence. In the first stage, pigeons were trained with two CSs (X and Y) and two different types of food (f1 and f2) as the USs. The occasion setters (A and B) signaled which type of food would occur after a given CS. Thus A signaled that stimulus X would be followed by f1 whereas stimulus Y would be followed by a f2; B signaled the reverse relation between the CSs and the food types. In a second phase of training the occasion-setting stimuli continued to be followed by X and Y as in the first phase, but these two old CSs were now presented in compound with two new CSs (S and D). When S (for Same outcome predicted) was the new CS, the food given was the same as that previously predicted by the combination of occasion setter and old CS; when D (for Different outcome) was the added CS, the food given was of the “wrong” type (see Table 1.5 for a summary of the contingencies).

This experimental design constitutes a version of the blocking procedure in which a new CS is added to one that has already undergone reinforcement and the compound continues to be reinforced. It is well established that the added stimulus will fail to gain associative strength in these circumstances; blocking occurs because the outcome of the trial is already predicted by the pretrained CS. The question of interest was the extent to which the added

stimuli S and D would suffer from blocking. A final test phase, in which stimuli S and D were presented alone, showed that S controlled less responding than D, indicating blocking had been more effective for S than for D. The implication is that the outcome of the stage-two trials had been well predicted on those occasions on which S was the added stimulus, but less well predicted on those on which D was the added stimulus. As Table 1.5 shows, the other individual stimulus elements (A and B, X and Y), had all received equal training as predictors of both food types. What distinguished S trials from D trials was that in the former the *combination* of occasion setter and CS predicted what food type would occur in stage two, whereas in the latter it did not. We may conclude that the occasion-setting feature supplies information about what US will follow what CS—just what would be expected on the basis of the associative structure shown in Figure 1.10c.

Configural Accounts of Occasion Setting

Discriminating Stimulus Patterns

It has long been known (e.g., Woodbury, 1943) that animals can learn discriminations in which the critical stimulus is a pattern or configuration of events. For example, in the procedure referred to as negative patterning, the animal is required to discriminate between a compound stimulus and its elements—the elements A and X when presented separately are each reinforced, but the AX compound is not. With extended training, the animal comes to respond to A and to X but not to the compound. Such a discrimination could not be achieved if the response to the compound was determined simply by the sum of the associative strengths of its elements. In order to explain this result it has been suggested that the compound should be seen as constituting a further, configural cue, distinct from those

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provided by A and X alone (Rescorla, 1972, 1973b). This requires a conceptual nervous system in which the stimuli are represented by three nodes, one activated by A, one by X, and one by the combination of the two as in Figure 1.11a. Standard learning rules (e.g., Rescorla & Wagner, 1972) can then predict that the A and X nodes will each acquire excitatory links with the US node and that the configural (AX) node will acquire inhibition enough to counteract the excitatory influence of the individual element nodes (as depicted in Figure 1.11a).

Although adequate to meet the explanatory demands of this particular case, the structure shown in Figure 1.11a has some problems. At the empirical level, other, more complex patterning discriminations prove difficult to explain in these terms (see, e.g., Pearce, 1987, 1994). More generally, although one might allow that animals come equipped with a range of nodes sensitive to any and all of the events that experimenters might judge to be simple stimulus elements, it seems implausible to assume that they also have nodes available and ready to respond to all possible combinations of these elements. The response to these problems has been to depart from the simple associative structure that has served so far, in which all stimulus nodes are capable of being activated directly by environmental events, and to adopt instead a multilayer network incorporating what have been called *hidden units*. Figure 1.11b presents an example of such a network as it might apply to the negative patterning discrimination. Here the node marked AX represents a hidden unit, activated not by events in the world but by inputs from the element nodes, A and X. A network of this sort allows that conditioning procedures can change the effectiveness of links between the US node and other nodes in the usual way; but it also allows the possibility that experience might influence the links between simple stimulus nodes and hidden units—that

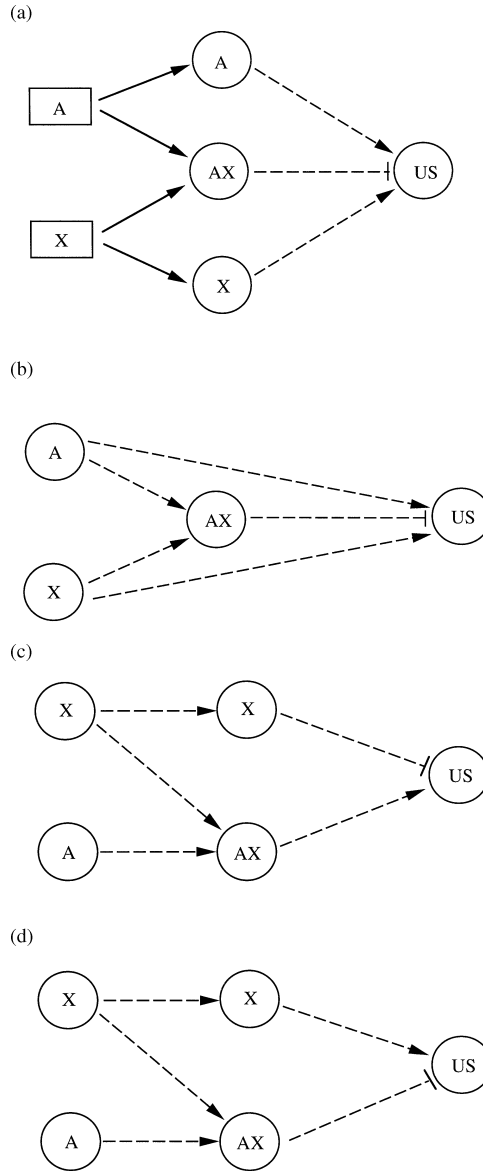


Figure 1.11 Possible associative structures for configural learning.

NOTE: In (a) the node sensitive to the configure A and X has the same status as the other nodes; in (b) this node is a hidden unit that is not accessed directly by events in the world. The multilayered structures (derived from Pearce, 1994) shown in (c) and (d) provide possible configural interpretations for feature-positive and feature-negative learning, respectively. Conventions are as given for Figure 1.1.

experience might “create” appropriate configural nodes.

Multilayer networks of the sort shown in Figure 1.11b come in many different versions. There are various views, for instance, as to what rules govern the activation of configural units and as to whether or not hidden units always mediate the connections between input units (even those corresponding to individual stimulus elements) and the US node (see, e.g., Brandon & Wagner, 1998; Pearce, 1994; Schamjuk & DiCarlo, 1992; Wagner & Brandon, 2001). It may be apparent, however, that the basic principle embodied by all these theories has the capacity to supply an explanation for occasion-setting effects. We have described feature positive and feature negative discriminations as involving conditional relationships, and the modulatory account developed above expresses this conditionality in the associative structure it employs (Figure 1.10c). But it is also possible to characterize these tasks as requiring a discrimination between stimulus patterns (with the AX pattern or configuration predicting one outcome and the X element alone another). Examples of the (rather different) associative structures generated by this latter perspective are presented in Figure 1.11. These structures (based on Pearce’s, 1994, configural theory) postulate a hidden unit corresponding to each of the two patterns of stimulation (i.e., X alone and the AX compound) experienced by the animal. Standard associative learning rules then result in the formation of excitatory or inhibitory associations between the hidden units and the US unit. In the feature positive case (Figure 1.11c), the AX unit forms an excitatory link and the X unit an inhibitory link; in the feature negative case (Figure 1.11d), the reverse pattern is established.

Choosing between the Accounts

The modulatory and configural accounts of occasion setting are clearly saying different

things. One way of characterizing the difference is to say that in the modulatory account the feature operates on the CS-US complex (for the feature positive case this may be symbolized as $A \rightarrow \{X-US\}$) whereas in the configural account a complex stimulus event operates on the US (symbolized as $\{AX\} \rightarrow US$). Nonetheless, it proves exceedingly difficult to devise an experimental test that allows choice between the alternatives. Both predict, for example, that the effect of the feature will be specific to the X-US combination with which it was trained (the transfer test results described above). Holland (1992) has carefully considered a range of other possible ways in which the rival theories might be distinguished, without reaching any decisive conclusion. It may be that the choice between the accounts will depend on consideration of data from procedures other than those employed for instrumental and Pavlovian conditioning. A particular strength of the configural account is its ability to explain the results from studies on complex discriminations in which subjects are required to categorize stimuli varying on a range of different dimensions—if it is necessary to use a configural theory to deal with these results, it may be deemed parsimonious to employ this same sort of theory when it comes to occasion setting.

But before discarding the modulatory account on these grounds, we should note two observations that indicate that it may still have a role to play. The first concerns the explanation of stimulus control in instrumental learning. Our analysis of this phenomenon, it will be recalled, led to the conclusion that the discriminative stimulus operates by modulating the effectiveness of the R-outcome association. No one has seriously suggested a configural interpretation of this phenomenon and accordingly we must acknowledge the reality of modulation in this case at least. And if modulation occurs in instrumental conditioning, might it not also occur in some

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Table 1.6 Design of Experiment by Honey and Watt (1998).

Stage 1	Stage 2	Test
A: $X \rightarrow f/A: Y-$		
B: $X \rightarrow f/B: Y-$	A \rightarrow shock	B > D
C: $X-/C: Y \rightarrow f$	C-	
D: $X-/D: Y \rightarrow f$		

NOTE: X and Y: Pavlovian conditioned stimuli; A, B, C, and D: occasion setters; f: food.

Pavlovian procedures? The second observation comes from an ingenious experiment by Honey and Watt (1998) designed to show such an effect.

The design of the experiment is outlined in Table 1.6. Rats were trained initially on a set of conditional discriminations in which two visual stimuli, X and Y, were followed by food on some trials but on others were nonreinforced. The outcome of the trial depended on the nature of the feature stimulus that preceded the auditory cue. When this was either A or B, X was reinforced and Y was not; when it was either C or D, Y was reinforced and X was not. This arrangement ensured that X, Y, and food all occurred equally often along with each of the feature stimuli. After extensive training, the animals learned to respond appropriately. The configural interpretation of this achievement holds that particular combinations of cues become associated with food or its omission; the animals learn $\{AX\} \rightarrow$ food, $\{CX\} \rightarrow$ no food, and so on. The modulatory account suggests that the feature stimuli acquire the power to control the effectiveness of particular CS-US associations (e.g., $A \rightarrow \{X\text{-food}\}$; $C \rightarrow \{X\text{-no food}\}$, and so on. To decide between these alternatives, Honey and Watt (1998) made use of the phenomenon known as acquired equivalence—the fact that generalization between quite different stimuli can be enhanced by initial training that establishes a common associate for them. (See, e.g., Honey & Hall, 1989; the effect is some-

times referred to as mediated generalization, reflecting the assumption that the enhanced generalization is mediated by the acquisition of strength by the associate that is shared by the critical cues.) In a second phase of training, they gave trials in which feature A, presented alone, was paired with shock so that it acquired the power to suppress ongoing behavior; feature C was also presented but in the absence of shock. The final test phase showed that feature B was also able to elicit response suppression whereas D was not. Without special elaboration, the configural account has no grounds to predict such differential generalization. But if we assume that A and B hold in common the ability to activate a given CS-US combination (an ability not shared by C and D), then differential generalization from A to B and from C to D can be predicted. In short, the outcome is what would be expected on the basis of the modulatory account of the acquisition of the original discrimination.

CONCLUSION

We began this chapter by postulating a conceptual nervous system consisting of nodes that correspond to those events that the experimenter chooses to describe as “stimuli” and “responses.” A stimulus in the external world is assumed to generate activity in its representative node; activity in a response node equates to the occurrence of a particular form of behavior. We further postulated that the training procedures employed in instrumental and Pavlovian conditioning result in the formation of new connections between nodes. Our central concern in this chapter has been to determine the pattern of connections (i.e., the associative structures) that are established by these procedures. Detailed discussion of process or function (as opposed to structure) has, accordingly, been outside the scope of

this chapter. To get the analysis of structures under way we adopted only very minimal assumptions about the conditions in which associations are formed and the effects that they have on nodes. For the former we assumed that an association will be formed between two nodes when both are activated concurrently (i.e., we adopted a simple contiguity principle); for the latter, we assumed that the existence of an associative link allows activity in one node to generate activity in another. It is time now to review how these simple principles have fared in the light of the experimental data.

For simple excitatory conditioning these assumptions fare tolerably well. The basic features of excitatory Pavlovian conditioning can be explained in terms of the formation of an association between the CS node and the US node; for instrumental excitatory conditioning the association is between the response node and one representing the outcome. In both cases, an S-R connection may also play a role. For both cases it also proves necessary to allow that the sensory and affective properties of the US (or outcome) may be represented by separate nodes, each capable of entering into association with other nodes. This elaboration requires no new assumptions. More fundamental is the suggestion that the nature of the activity engendered in a US node by way of an associative link is different in kind from that produced by presentation of the US itself (although, as was shown in Figure 1.1b, it may be possible to express this notion in structural terms without the need to introduce a new type of nodal activity).

Our survey of experimental studies of extinction showed that the phenomena can again be accommodated by the assumption that extinction procedures result in the formation of new links between CS and US, or between response and outcome. But here it is necessary to postulate a new process. The effect of these

links is not to excite but to inhibit activity in the target node (a process that we have identified with a raising of the node's threshold for sensitivity to excitatory influence). Again, it is possible to complicate the structure and maintain the assumption that conditioning consists solely of the formation of excitatory links between concurrently activated nodes. This is achieved by postulating the existence of a no-US node to which the extinguished CS forms an excitatory link (see Figure 1.6). But it still remains necessary to allow the existence of an inhibitory process (in this case, in the form of an intrinsic inhibitory connection between the no-US node and the US node).

Whichever of the rival accounts we adopt, explanation of the effects revealed in studies of complex (conditional) conditioning procedures requires a new degree of elaboration of our basic assumptions. The modulatory account requires quite a new process. Although the principle that the feature stimulus has its effects by way of an associative link is standard, the effect of this link is not to excite (or even inhibit) activity in another node—rather it is assumed that the link allows the feature to control the flow of activity along some other associative link. The configural account avoids the need to postulate a new process, but does so at the expense of creating an associative structure with a new level of complexity. The introduction of a new layer of hidden units serving a purely computational function means that nodes can no longer be directly identified with events in the external world and the simplicity of the original associative explanation of basic conditioning is lost. Neither of these accounts is wholly satisfactory and it is to be hoped that further research (and theorizing) may come up with some other associative structure in which the best features of both of the current rival accounts can be incorporated.

Finally, it is worth noting that, in spite of the need to add these elaborations, the basic

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explanatory scheme adopted by students of conditioning (in which learning consists of changes in the strength of connections between simple units) has proved to have very wide explanatory powers. The rediscovery of this scheme in recent years by advocates of connectionism (seemingly in ignorance, in some cases, of its long history in the conditioning laboratory) has extended the range of phenomena that the scheme is applied to and has brought it to the notice of a larger audience. But experimental studies using conditioning techniques and directed toward refining our understanding of basic associative principles still continue and we may hope, for the future, that the outcome of these studies will inform the work of those theorists who are attempting to provide an associative (or connectionist) account of cognition generally.

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