

THEORIES OF ASSOCIATIVE LEARNING IN ANIMALS

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■ **Abstract** Theories of associative learning are concerned with the factors that govern association formation when two stimuli are presented together. In this article we review the relative merits of the currently influential theories of associative learning. Some theories focus on the role of attention in association formation, but differ in the rules they propose for determining whether or not attention is paid to a stimulus. Other theories focus on the nature of the association that is formed, but differ as to whether this association is regarded as elemental, configural, or hierarchical. Recent developments involve modifications to existing theories in order to account for associative learning between two stimuli, A and B, when A is accompanied, not by B, but by a stimulus that has been paired with B. The implications of the theories for understanding how humans derive causal judgments and solve categorization problems is considered.

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INTRODUCTION

The first theory of associative learning in animals was proposed more than a century ago by Thorndike (1898). Thorndike argued that learning consists of the formation of connections between stimuli and responses and that these connections are formed whenever a response is followed by reward. Thorndike's proposals formed the basis of a number of subsequent theories of associative learning, all of which shared the assumption that learning is based on the growth of stimulus-response connections (e.g. Hull 1943). Although stimulus-response connections are still believed to play a role in learning and behavior (Dickinson 1994, Rescorla 1991a), theories of associative learning since 1970 have focused more on stimulus-stimulus than stimulus-response connections. One reason for this change is purely practical. Thorndike based his theorizing on studies of instrumental conditioning in which a response, such as pressing a lever, resulted in the delivery of a reward, such as food. The problem with this design is that the animal, not the experimenter, determines when reward will be delivered and it is difficult to control when each learning episode occurs. Researchers accordingly turned their attention to Pavlovian conditioning, in which a neutral stimulus, such as a tone, signals the delivery of a biologically significant event, such as food. Evidence of learning in this task, where each training episode is entirely under the control of the experimenter, is found when the neutral stimulus (the conditioned stimulus, CS) elicits a response such as salivation (the conditioned response, CR), which is appropriate to the imminent delivery of the biologically significant event (the unconditioned stimulus, US).

Because Pavlovian conditioning involves the presentation two stimuli paired together, it became natural to assume that learning about this relationship depends upon the growth of stimulus-stimulus connections. In keeping with this assumption, experiments revealed that the CS is indeed able to activate a representation, or memory, of the US with which it has been paired (Rescorla 1973).

Pavlovian conditioning merits study for two important reasons. First, as a behavioral phenomenon it plays a fundamental role in both animal and human behavior. For example, it is a mechanism that allows animals to adapt to imminent biologically significant events (Hollis 1982, 1997), and in humans it is further involved in abnormal behavior such as drug abuse (Siegel 1989) and anxiety disorders (e.g. Bouton et al 2000). Second, classical conditioning provides a valuable method for studying how animals and humans learn to associate two events. The most influential theory of associative learning was proposed by Rescorla & Wagner (1972, Wagner & Rescorla 1972). Although more than 25 years have elapsed since it was published, there is no sign of a decline in the influence of this theory. According to the Social Science Citation Index, between 1981 and 1985 it was cited on more than 330 occasions, whereas between 1995 and 1999 it was

cited on more than 480 occasions. The Rescorla-Wagner model has not gone unchallenged. A variety of experimental findings have been reported that are difficult for the theory to explain (see Miller et al 1995), and some of these findings have prompted alternative theories of associative learning. The purpose of this article is to review these theories. We do not consider each theory in detail. Instead, we focus on the extent to which the various theories overcome shortcomings of the Rescorla-Wagner theory. By doing so, we hope to convey an accurate impression of the issues that are of current theoretical concern in the study of associative learning in animals, why they are of concern, and how close they are to being resolved.

THE RESCORLA-WAGNER THEORY

According to contemporary thinking, the strength of a Pavlovian CR depends upon the strength of the connection between internal representations of the CS and the US or, as it is frequently referred to, the associative strength of the CS. Equation 1 was proposed by Rescorla & Wagner (1972) to account for the change in associative strength of stimulus A, ΔV_A , on a conditioning trial.

$$\Delta V_A = \alpha\beta(\lambda - V_T) \quad (1)$$

The change in associative strength is directly related to the discrepancy between an asymptotic value set by the magnitude of the US, λ , and the sum of the associative strengths of all the stimuli present on the trial, V_T . The extent of this change is modified by two learning-rate parameters with values between 0 and 1. The value of α is determined by the salience of the CS, and that of β by characteristics of the reinforcer. By far the most important feature of the Rescorla-Wagner (1972) theory is the assumption that the change in associative strength of a stimulus on any trial is determined by the discrepancy between λ and the sum of the associative strengths of all the stimuli present on the trial in question. In previous theories, the degree of learning about a stimulus was determined by the discrepancy between the asymptote for conditioning and the associative strength of the stimulus by itself (e.g. Bush & Mosteller 1955). As a consequence of this difference, the Rescorla-Wagner (1972) theory is able to explain a far wider range of experimental findings than its predecessors. One such finding is blocking. Kamin (1969) demonstrated that if rats receive foot shock after one stimulus, A, and then A is paired with another stimulus, B, and the AB compound is paired with the same shock, then very little is learned about the relationship between B and shock. According to Equation 1, when B is introduced for conditioning, the increment in its associative strength will be given by the discrepancy between λ and the combined associative strengths of A and B. The pretraining with A will mean this discrepancy is close to zero, and B will gain little associative strength.

Other findings that are well accounted for by the theory concern the effects of nonreinforcement. Suppose stimulus A is paired with a US and the compound AB is followed by nothing. The model assumes that λ will be zero on nonreinforced trials and B will therefore acquire negative associative strength. As a consequence,

conditioning with B is predicted to progress slowly if it should be paired with the same US that was paired with A; the presence of B is also predicted to suppress responding in the presence of any CS that has been paired with the US. That is, the discrimination training with B is correctly predicted to result in B functioning as a conditioned inhibitor. A great deal of the popularity of the Rescorla-Wagner model can be attributed to the successful predictions it made concerning such stimulus selection effects as blocking, and to the account it offered for inhibitory conditioning. Furthermore, despite the shortcomings of the theory enumerated below, most contemporary theories of conditioning adopt an error-correction principle similar to that advocated by Rescorla and Wagner to account for such effects as blocking and conditioned inhibition.

THE ASSOCIABILITY OF A STIMULUS DOES NOT REMAIN CONSTANT

In terms of Equation 1, the ease with which the associative strength of a CS can change is determined by the value of the parameter, α , which reflects the conditionability, or associability of a stimulus. Wagner & Rescorla (1972) proposed that the value of α was determined by the intensity of the CS. They also acknowledged that the value of α could change through exposure to a stimulus, but they did not state formally how this change might take place. Latent inhibition provides one example of how exposure to a stimulus might influence its associability. The first demonstration of latent inhibition was provided by Lubow & Moore (1959), who found that repeatedly presenting a CS by itself significantly retarded subsequent conditioning when the CS was paired with a US. That is, simple exposure to a stimulus was sufficient to reduce its associability. We now consider three different accounts for the way in which the associability of a stimulus can be altered (for an explanation of latent inhibition that does not depend upon associability changes see Bouton 1993).

Wagner

Although the Rescorla-Wagner (1972) model can be interpreted as a rule describing the growth of associations between internal representations of the CS and US, it does not explain how these representations are formed, what they consist of, and how they influence performance. Wagner (1981; see also Brandon & Wagner 1998, Wagner & Brandon 1989) has addressed some of these issues in a theory of standard operating procedures (SOP) in memory. Any stimulus is assumed to excite a node that consists of a set of elements. Normally the elements are in an inactive state, but they may occasionally be in one of two states of activation, A1 and A2. An A1 state of activation can be likened to the stimulus being at the focus of attention, or in a state of rehearsal; the A2 state can be likened to the stimulus being at the margin of attention. The only route by which elements in a node may enter the A1 state is by presenting the stimulus itself, but there are two

routes by which elements may enter the A2 state. One route is through decay from the A1 state. The other route depends upon previously formed associations. If a CS has been paired with a US, subsequent presentations of the CS will excite US elements directly to the A2 state. Once elements are in the A2 state they can move only into the inactive state, even if the stimulus to which they are related should be presented.

The distinction between A1 and A2 states of activation is important because Wagner (1981) argued that the associative strength of a CS can be changed only when its elements are in the A1 state. To explain latent inhibition he suggested that repeatedly presenting a stimulus in a given context will encourage the growth of associations between the context and the stimulus. These associations will then allow the context to activate an A2 representation of the preexposed stimulus and thus prevent the CS, when it is presented for conditioning, from activating an A1 representation that is essential if learning is to take place. One prediction that follows from this account is that latent inhibition will be context specific. If preexposure is conducted in one context, and the CS is presented in a different context for conditioning, the new context will be less likely than the old context to excite a representation of the CS into the A2 state. As a consequence, the CS should now be able to excite its representation into the A1 state and enter readily into an association with the US. Experiments have confirmed the context-specific nature of latent inhibition with a variety of methods (Channell & Hall 1983, Hall & Channell 1985, Hall & Minor 1984, Lovibond et al 1984, Rosas & Bouton 1997). According to Wagner's (1981) theory, it should also be possible to reduce latent inhibition by exposing animals to the context after preexposure, but before conditioning, and thereby extinguish the context-stimulus associations. Westbrook et al (1981) cite evidence in support of this prediction, but both Baker & Mercier (1982) and Hall & Minor (1984) found no effect of extensive exposure to the context on latent inhibition. These findings are difficult to interpret, however, because we do not know if sufficient exposure to the context was given in order for the context-CS associations to be extinguished.

The analysis of latent inhibition in terms of SOP has implications for habituation, the decrease in unconditioned responding to a repeatedly presented stimulus. If we assume that the response evoked by the stimulus depends on it being in the A1 state, then habituation may result (in part) from the context entering into an association with the stimulus and retrieving it into A2 instead of A1. This associative perspective on habituation predicts that habituation (like latent inhibition) will be context specific. Although experiments have failed to confirm this prediction (Marlin & Miller 1981), the role for context may depend on the response system investigated (Jordan et al 2000). For example, habituation of responding to drug stimuli (tolerance) often appears to be context specific (Baker & Tiffany 1985, Siegel 1989).

A further prediction of the SOP theory is that it should be possible to disrupt conditioning by presenting a CS shortly before a trial in which the same CS is paired with a US. The initial presentation will put the representation of the CS into the A1 state, which will decay to the A2 state. If the CS should be presented while

its representation is in the A2 state, it will be unable to activate its A1 representation and conditioning will not be effective. Evidence in support of this analysis comes from studies in which the adverse consequences of pairing a flavor with illness have been mitigated by allowing rats brief access to the flavor 3.5 h before the conditioning episode (Best & Gemberling 1977; see also Westbrook et al 1981). Best & Gemberling (1977) further demonstrated that this effect is not apparent when the interval between the two presentations of the flavor is increased to 23.5 h. At this longer interval, the states of activation engendered by the first exposure to the CS will have had time to decay to the inactive state, thus permitting the CS on its second exposure to activate its A1 representation and for conditioning to progress as normal. Best et al (1979) also demonstrated that interposing a distracting event between the first and second presentation of the CS reduced the disruptive influence of the first CS presentation on subsequent conditioning. Such a result is consistent with Wagner's (1981) proposal that a limited number of stimuli can be in the A2 state at any one time.

The idea that latent inhibition results from the development of associations between the preexposed stimulus and the context can also be found in the theory of McLaren et al (1989), which has been used to explain why preexposure to two stimuli, or two stimulus compounds, can facilitate a discrimination between them: perceptual learning. Suppose two compounds, AX and BX, are repeatedly presented. These compounds have both unique elements (A and B) and a common element (X). According to McLaren et al, one consequence of this treatment is that it will allow the components of the compounds to enter into associations with each other and with the experimental context. As these associations gain in strength, the associability of the stimuli will eventually decline. Because the common element, X, is presented more often than the unique features, A and B, it follows that the associability of X will decline more rapidly than that of A and B. If the two compounds should be used for a discrimination after they have been preexposed, the relatively low associability of the common feature will ensure that the discrimination will be acquired more readily than when the compounds are novel and the associability of the common feature is high. Evidence in support of these ideas has been reported by Mackintosh et al (1991) and Symonds & Hall (1995).

Mackintosh

Mackintosh (1975) proposed that the associability of a stimulus is determined by how accurately it predicts reinforcement. If the CS is the best available predictor of a US, its associability will be high. However, if the stimulus is a poor predictor of reinforcement, its associability will be low. Stimulus A is regarded as a good predictor of the US if the discrepancy between its current associative strength and the asymptote for conditioning ($\lambda - V_A$), is less than ($\lambda - V_X$), where V_X is given by the sum of the associative strengths of all the stimuli apart from A that accompany A. Stimulus A is regarded as a poor predictor of the US if ($\lambda - V_A$) is greater

than or equal to $(\lambda - V_X)$. In these conditions the associability of A is predicted to decrease. To explain latent inhibition, Mackintosh (1975) proposed that during stimulus preexposure, the event that follows a CS—nothing—is predicted equally well by the stimuli accompanying the CS as by the CS itself. On these occasions, therefore, the expression $(\lambda - V_A)$ will be equal to the value of $(\lambda - V_X)$ and there will be a loss in the associability of A.

Equation 2 shows how the associability of Stimulus A, α_A , determined as above, influences the rate of conditioning with this stimulus. This equation differs in one important respect from the Rescorla-Wagner (1972) equation. On any trial, the change in associative strength of a stimulus is determined by the discrepancy $(\lambda - V_A)$ rather than $(\lambda - V_T)$. An important implication of this difference is that stimulus selection effects are not attributed to stimuli competing for a limited amount of associative strength, as the Rescorla-Wagner model implies. Instead, effects such as blocking occur because animals will pay little attention to, and hence learn rather little about, stimuli that are relatively poor predictors of the US. Although there is evidence to suggest that attentional processes akin to those envisaged by Mackintosh (1975) play a role in blocking (Dickinson et al 1976), there is also evidence that supports the analysis offered by Rescorla & Wagner (1972) for this effect (Balaz et al 1982). Blocking and related stimulus selection effects are thus likely to be multiply determined (Holland 1988).

$$\Delta V_A = \alpha_A \beta (\lambda - V_A) \quad (2)$$

A major problem for Mackintosh's theory (1975) rests with the prediction that attention to a stimulus will increase if it is the best available predictor of reinforcement. The fairest conclusion to draw from the many experiments that have been designed to test this prediction is that their findings are contradictory. Support for this prediction comes from studies that have compared the effects of intradimensional (ID) and extradimensional (ED) shifts on the acquisition of a discrimination (George & Pearce 1999, Mackintosh & Little 1969, Shepp & Eimas 1964). In these experiments animals are required to discriminate between patterns composed of elements from two dimensions. For example, they may be exposed to four patterns: red horizontal lines, red vertical lines, blue horizontal lines, and blue vertical lines. Initially, reward may be signaled by the two red patterns, but not the two blue patterns, thus making color the relevant dimension and orientation the irrelevant dimension. A new discrimination is then given for the test stage, based on four new patterns composed of new colors and new line orientations. For an ID shift, the new elements from the previously relevant dimension will signal reward, and for an ED shift the new elements from the previously irrelevant dimension will signal reward. In the experiments cited above, the new discrimination was acquired more rapidly when it involved the ID rather than the ED shift, which can be most readily explained by assuming that the training in the first stage encouraged animals to pay more attention to the relevant than the irrelevant dimension. Such a conclusion is clearly in keeping with the principles advocated by Mackintosh (1975).

Evidence less in keeping with the theory of Mackintosh (1975) is provided by Hall & Pearce (1979), who used a CS to signal a weak shock for 60 trials. The CS was then paired with a stronger shock, and they found that conditioning progressed more slowly than for a group that received the strong shock signaled by a novel CS. That is, pairing the CS with a weak shock resulted in latent inhibition (see also Hall & Pearce 1982). According to Mackintosh's theory (1975), the training with the weak shock should have enhanced the associability of the CS and resulted in rapid rather than slow conditioning during the second phase of the experiment. At present it is not clear how the findings described by Hall & Pearce (1979) can be reconciled with successful demonstrations of an ID-ED effect.

Pearce and Hall

Pearce & Hall (1980) proposed that attention to a stimulus is necessary while subjects are learning about its significance, but once learning has reached a stable asymptote no further attention to the stimulus is required. Obviously, the animal will need to detect the stimulus in order to respond appropriately in its presence, but Pearce and Hall regarded this as a rather different form of attention than the one necessary for learning. They therefore proposed that attention to a CS, and hence its associability, will be governed by Equation 3. The associability of Stimulus A on trial n , is determined by the absolute value of the discrepancy $\lambda - V_T$ for the previous occasion on which A was presented (where V_T is determined in the same way as for the Rescorla-Wagner theory).

$$\alpha_{An} = |\lambda - V_T|_{n-1} \quad (3)$$

The associability of a stimulus will be high when it has been followed by a US that is unexpected (when $\lambda - V_T$ is high), but its associability will be low when it has been followed by a US that is expected (when $\lambda - V_T$ is low). The outcome of the experiment by Hall & Pearce (1979) that has just been mentioned is consistent with these proposals. The large number of pairings between the CS and the weak shock in the first stage of the experiment would reduce the associability of the CS by ensuring that it was an accurate predictor of the shock. The low associability of the CS would then be responsible for the slow conditioning observed during the second stage when the weak shock was replaced with a stronger shock. Wagner's theory (1981) can also explain the findings by Hall & Pearce (1979). During conditioning with the weak shock, the CS will enter into an association with the context, and the consequent loss of associability will disrupt conditioning with the large shock (Swartzentruber & Bouton 1986). However, experiments that have shown that the associability of a stimulus is higher when it is an inaccurate than an accurate predictor of the events that follow it lend unique support to the Pearce-Hall (1980) theory (Hall & Pearce 1982, Swan & Pearce 1988, Wilson et al 1992).

There is, therefore, evidence in support of each of the three theories considered in this section. Given the diverse nature of these theories, it is likely that there is

more than one mechanism for altering stimulus associability, and that the different mechanisms are governed by different principles.

CONFIGURAL OR ELEMENTAL ASSOCIATIONS

The theories considered thus far all share the assumption that when two or more stimuli are presented at the same time for conditioning, each element may enter into an association with the reinforcer. In general, such elemental theories further assume that responding in the presence of the compound is determined by the sum of the associative strengths of its constituents. As an alternative, configural theories are based on the assumption that conditioning with a compound results in a unitary representation of the compound entering into a single association with the reinforcer (Friedman & Gelfand 1964; Gulliksen & Wolffe 1938; Pearce 1987, 1994). Responding in the presence of the compound is then determined by its own associative strength, together with any associative strength that generalizes to it from similar compounds that have also taken part in conditioning.

Before reviewing the evidence that relates to these contrasting theoretical positions, we should clarify that a strictly elemental theory needs to be elaborated if it is to explain the solution of certain discriminations. Wagner & Rescorla (1972) acknowledged the need for such an elaboration in order to explain the ability of animals to solve discriminations such as negative patterning. For this discrimination a US is presented after each of two stimuli when they are presented alone, but not when they are presented together (A+ B+ ABo). As the theory has been described thus far, it predicts that the associative properties of A and B will summate so that responding during the nonreinforced trials with AB will be consistently stronger, rather than weaker, than during either A or B alone. To avoid making this incorrect prediction, Wagner & Rescorla (1972) proposed that compounds create unique, configural cues that function in the same way as normal stimuli. Hence, for negative patterning, the cue created by the compound AB will acquire negative associative strength and eventually result in little or no responding during the compound. Even though a theory might assume the existence of such cues, it must still be regarded as an elemental theory because each element of the compound (including the configural cue) has the potential for entering into a separate association with the reinforcer.

According to Pearce (1987, 1994), conditioning with a pattern of stimulation, P, will result in the development of a single association with the US. The strength of this association will be referred to as E_p . Should a new pattern, P', be presented on a subsequent trial, then it will not itself possess any associative strength. However, if P' is similar to P it will elicit a response through stimulus generalization. The strength of the response will be determined by the similarity of P to P', ${}_pS_{P'}$, multiplied by the associative strength of P, that is, ${}_pS_{P'} * E_p$. The similarity of P and P' (which can vary between 0 and 1) is a function of the proportion of common elements they share. Formally, ${}_pS_{P'}$ is given by the expression $N_C^2 / (N_P * N_{P'})$,

where the number of stimulus elements in P and P' determine N_P and $N_{P'}$, and N_C is the number of elements common to both patterns. Equation 4, which can be viewed as a variation on the Rescorla-Wagner (1972) learning rule (Equation 1), shows that the change in associative strength of P is determined by the difference between λ and P's own associative strength plus that which generalizes to it from similar patterns. As before, β is related to properties of the US. Equation 4 does not contain a parameter that reflects stimulus salience because this property of the CS exerts its influence by contributing to the degree of generalization from one pattern to another. [Pearce et al (1998) discuss how these ideas can be developed to take account of changes in stimulus associability.]

$$\Delta E_P = \beta(\lambda - (E_P + {}_P S_{P'} * E_{P'})) \quad (4)$$

In contrast to elemental theories, no special assumptions are necessary for configural theory to explain the successful solution of negative patterning discriminations. If trials are given in which a US is presented after A and B alone, but not after the compound, the theory predicts that representations of A and B will enter into excitatory (positive) associations and a representation of AB will enter into an inhibitory (negative) association. Thus, whenever AB is presented, generalized excitation from A and B will encourage responding, but this will be counteracted by the inhibition associated with AB.

Elemental and configural theories of associative learning differ in the predictions they make concerning an effect known as one-trial overshadowing. Mackintosh (1971; James & Wagner 1980) has shown that the presence of one stimulus will overshadow or restrict conditioning with another stimulus if they are presented together for a single compound conditioning trial. According to Rescorla & Wagner (1972), overshadowing should not occur in these circumstances because for the first trial with a compound CS, each component will gain as much associative strength as if it were conditioned in isolation. In contrast, configural theory correctly predicts that overshadowing will be seen after a single compound trial because of the generalization decrement incurred by the transition from training with a compound to testing with an element.

A further difference between elemental and configural theories rests with the predictions they make concerning retroactive interference. In keeping with a number of connectionist networks that represent patterns of stimulation in a distributed fashion, elemental theories predict that retroactive interference can be catastrophic (McCloskey & Cohen 1989, Page 2000). In contrast, configural theories make less dramatic predictions about some forms of retroactive interference. An experiment by Pearce & Wilson (1991) highlights this difference between the two classes of theory. Rats first received a feature negative discrimination (A+/AB0) with food presented after A, but not after AB. Stimulus B was then paired with food, before subjects were tested with the original discrimination. An elemental solution to the original discrimination requires that B develop negative associative strength, which will be transformed to positive associative strength by pairing B with food. Upon the reintroduction of the discrimination, the combination of the associative

strengths of A and B is then predicted to reverse the original discrimination and produce stronger responding during AB than A. The test trials revealed no support for this prediction, although there was some recovery of responding during AB. This outcome is consistent with configural theory, which predicts that the training in Stages 1 and 2 will result, first, in AB entering into an inhibitory association and, second, B entering into an excitatory association. When AB is then presented for testing, its original inhibitory properties will be reduced by excitatory generalization from B, but this generalization will be incomplete, and AB will continue to elicit a weaker response than A. It should be noted that configural and many elemental theories still predict catastrophic interference in some simple tasks, for instance conditioning followed by extinction. Effects such as spontaneous recovery indicate that extinction does not necessarily erase the effects of conditioning.

Configural and elemental theories of associative learning also differ in the predictions they make concerning the influence of similarity on discrimination learning. A general prediction of configural theory is that a discrimination between two patterns of stimulation will be more difficult when they are similar than when they are different. Elemental theories do not always make this prediction. Redhead & Pearce (1995a) trained a group of pigeons with an A+ BC+ ABCo discrimination, in which food was presented after stimulus A, after compound BC, but not after the triple-element compound, ABC. According to the principles outlined above, ABC is more similar to BC than to A, and configural theory therefore predicts that the discrimination between BC and ABC will be more difficult than between A and ABC. The results confirmed this prediction.

Surprisingly, elemental theories of associative learning predict the opposite outcome. According to Equation 1, for instance, the trials with BC will allow both B and C to gain excitatory strength. The summation of these strengths will then lead to responding during BC being consistently stronger than during A. Because responding is reduced on the nonreinforced trials with ABC, it follows that the discrimination between BC and ABC will be more marked than between A and ABC, but this was not the case (for related confirmations of configural theory, see Pearce & Redhead 1998, Redhead & Pearce 1995b).

Another method for choosing between configural and elemental theories of associative learning is to use a variety of elements and compounds to signal a US, and then to conduct a test trial with a novel combination of stimuli. Elemental theories assume that responding to the test compound will be determined by the sum of the associative strengths of its components, whereas configural theory assumes that responding will be determined by generalization from the various training patterns to the test compound. Unfortunately, attempts to evaluate these different theoretical accounts have led to conflicting results. A number of studies, have lent more support to configural than elemental theories (Aydin & Pearce 1997, Nakajima 1997, Nakajima & Urushihara 1999), whereas other studies have lent more support to elemental than configural theories (Rescorla 1997, 1999).

There are, therefore, good reasons for believing that associations based on the entire pattern of stimulation that signals a US are acquired during conditioning.

However, it is too early to say whether these associations underlie all aspects of associative learning, or whether conditioned responding is a consequence of the influence of such configural associations in some circumstances and elemental associations in others (Fanselow 1999, Williams et al 1994). If the latter should be the case, then one important goal for future research is to identify when animals will rely on one sort of association rather than the other. It will also be important to develop a theory that explicates how these different types of association interact with each other.

CONDITIONAL ASSOCIATIONS

Learning, as implied by Rescorla & Wagner (1972), consists of a change in the strength of an association between the CS and the US. During the early 1980s the results from a variety of experiments indicated that a CS may alternatively control responding in a manner that is independent of its direct association with the US. This type of effect is now known as occasion setting because one CS appears to “set the occasion for” responding to a second CS without entering into a direct association with the US (Holland 1985).

Occasion setting is most readily studied using either a feature-negative (A+/ABo) or a feature positive (Ao/AB+) discrimination in both of which responding during one stimulus, A, is controlled by the presence or absence of another stimulus, B. A successful solution of these discriminations is easily explained by all the theories discussed so far. For example, according to elemental theories, these discriminations will result in B gaining either positive or negative associative strength. However, when B (the so-called feature stimulus) either precedes or is considerably weaker in salience than A (the so-called target stimulus), B appears to become an occasion setter instead of a simple inhibitor or excitor (Holland 1985, 1989c).

At least three kinds of evidence suggest that occasion setters do not operate through direct excitatory or inhibitory associations with the US. First, several feature positive (Ao/AB+) experiments have used features and targets that evoke qualitatively different CRs (Rescorla 1985, Ross & Holland 1981). For example, in a study by Ross & Holland (1981) rats received the sequence light(B)-tone(A)-food, or the tone by itself without food. The normal CR to the light is rearing and to the tone it is head jerking. Even though the tone by itself eventually elicited little head jerking, this activity was enhanced considerably during the tone when it was preceded by the light. Thus, animals behaved as if the light enabled or activated the association between the tone and food. Second, occasion setters have unusual properties when they are tested with excitors that have been conditioned separately. An occasion setter may not influence responding to a conventional CS (Holland 1986, 1989a), but it will influence responding to a stimulus that has been the target in another occasion-setting discrimination (Holland 1989d, Lamarre & Holland 1987, Rescorla 1985) or has been conditioned and then extinguished (Rescorla

1985, Swartzentruber & Rescorla 1994, but see Bonardi & Hall 1994, Holland 1989b). Third, occasion setters can be less affected than conventional CSs by a change in their relationship with the US. When B is a positive occasion setter, it does not lose its ability to enable responding to A even after it has been extinguished through separate presentation without food (Holland 1989b). Similarly, when B is a negative occasion setter, separate reinforcement of it has less impact than when it is a simple inhibitor (Holland 1984). Rescorla (1991b) has even shown that separate reinforcement of a negative occasion setter can actually facilitate the learning of an A+/AB_o discrimination. Other evidence besides the three classic lines just described has also appeared. For example, rats generalize more between features that signal the same target-US relations than features that signal the same target and US in different combinations (Honey & Watt 1998). This sort of result suggests that animals may connect a feature with a particular target-US relation over and above the individual events themselves.

These findings all suggest that occasion setting discriminations are not necessarily controlled by simple B-US associations. They are thus generally viewed as being inconsistent with simple elemental theories of associative learning. In contrast, configural theories have fared better. For example, we have already shown that a configural model correctly predicts that reinforcing B after A+/AB_o training will have little impact on the discrimination (Pearce & Wilson 1991), and a similar argument would explain the lack of effect of nonreinforcing B after A_o/AB+ training. However, without elaboration, configural models are less able to deal with the fact that a transfer target's reinforcement history appears so important in determining whether an occasion setter will influence responding to it. Other findings that are also inconsistent with the Pearce model (Bouton & Nelson 1994, 1998; Holland 1989a; Honey & Watt 1998) seem more consistent with the idea that the animal often encodes the feature and target as separable elements in the compound.

Most theorists assume that occasion setting depends upon the feature modulating the target's association with the US in a hierarchical manner (but see Brandon & Wagner 1998). Holland (1983a, 1985) was perhaps the first to make this proposal by suggesting that the occasion setter excited or inhibited the association between the target and US. As it stands, this account predicts that the influence of an occasion setter should be confined to the CS with which it was originally trained but, as noted above, occasion setters can influence responding to targets from another occasion-setting discrimination. As an alternative explanation, Rescorla (1985) suggested that occasion setters are effective by either raising (negative occasion setter) or lowering (positive occasion setter) the threshold for activation of the US representation and thus alter the ease with which the target can elicit a response. Although this proposal explains how an occasion setter can influence responding to a stimulus with which it has never before been paired, it is unable to explain why the effects of an occasion setter can be specific to the target used during training (Holland 1985).

A third explanation for occasion setting is based on findings that suggest that conventional extinction results in a loss of responding through the development of

inhibitory associations, and that these associations are more affected by changes in context than the original excitatory associations (Bouton 1993, see below). Bouton & Nelson (1994, 1998; Nelson & Bouton 1997) suggested (a) that reinforcing and nonreinforcing the target during an occasion-setting discrimination will allow it to enter into excitatory and inhibitory associations with the US and (b) that the effects of the latter are more context specific than the former. The role of the occasion setter is either to activate or inhibit the target's inhibitory association with the US. A similar idea was independently derived in a connectionist treatment of occasion-setting phenomena (Schmajuk et al 1998). In that scheme, the target enters into an excitatory association with the US and also an inhibitory association that is mediated by a hidden unit. The occasion setter excites or inhibits the hidden unit, and thus the inhibitory target-US association. The occasion setter will "transfer" and influence responding to a new target as long as the new target has acquired this inhibitory association, either because the target has participated in an occasion-setting discrimination or because it has been conditioned and extinguished in a salient context (Lamoureux et al 1998). Interestingly, this mechanism was described as a "configural" one. One might say that the trend in research on conditional associations has been toward progressively refining the meaning of configural conditioning.

A SPECIAL ROLE FOR CONTEXT

One of the earliest triumphs of the Rescorla-Wagner (1972) model was the analysis that it offered for Rescorla's (1968) work showing the importance of the CS-US contingency for conditioning. Rescorla (1968) varied the probability with which a US could occur during both the presence and the absence of a CS. Conditioning was effective when the CS signaled an increase in the probability of the US, but conditioning was not effective when the probability of the US was the same in both the presence and absence of the CS. The model can explain this result by allowing the experimental context to be associated with the US like any other CS. When shock was presented frequently in the absence of the CS, the opportunity would arise for the growth of a strong context-US association that would then block conditioning with the CS.

The foregoing analysis encourages the view that a role for context may be important in many conditioning experiments. If the context functions as another CS, as the model assumes, then responding to a CS in a given context will always be affected by the strength of the association between the context and the US. Although the context does turn out to be important, its associative strength often is not. Consider extinction, which is particularly sensitive to a change of context. If conditioning takes place in one context, and extinction in a second context, then returning the animal to the original context typically results in some recovery from the effects of extinction (Bouton & King 1983, Bouton & Peck 1989). This renewal effect also occurs when the CS is tested in a third context (Bouton & Bolles 1979, Bouton & Brooks 1993), and when testing takes place in a second context

after conditioning and extinction have both occurred in the first context (Bouton & Ricker 1994). The last result implies that simple excitatory conditioning may be less affected than extinction by a context switch. That is, although extinction performance is usually disrupted by a context switch, conditioning performance is often not (Bouton & King 1983, Bouton & Peck 1989, Hall & Honey 1989, Kaye & Mackintosh 1990, Lovibond et al 1984).

Unfortunately, these findings are not easy to explain if it is assumed that a context functions in the same way as a normal CS. For example, it might be supposed that the renewal effect is a consequence of the context in which extinction takes place acquiring negative associative strength that protects the CS from extinction (Chorozyna 1962). However, there is no evidence that the extinction context acquires negative strength during the extinction phase (Bouton & King 1983, Bouton & Swartzentruber 1986). Alternatively, it might be assumed that the context in which conditioning is conducted acquires positive associative strength, which through summation, would boost responding to the CS at the time of the renewal test. Once again, however, there is little evidence to support the operation of this mechanism in typical procedures (Bouton & King 1983, Bouton & Swartzentruber 1986). The renewal effect is also difficult to explain by configural models emphasizing generalization decrement. The fact that there is little or no decrement in responding when the CS is first presented in the new context for extinction suggests that there should be an equally small decrement in the effects of extinction when the CS is returned to the original context for the renewal test.

In addition to these difficulties, other research has shown that contextual associative strength is neither necessary nor sufficient for a context to control responding to a CS. Thus, contexts may influence responding to a CS when independent tests have failed to reveal any evidence of a context-US associations (Bouton & King 1983, Bouton & Swartzentruber 1986). Conversely, responding to a CS can be unaffected by demonstrable context-US associations (Bouton 1984, Bouton & King 1986). Interestingly, context-US associations created after extinction do augment responding to an extinguished CS, but not a CS for which responding has not been extinguished (Bouton 1984, Bouton & King 1986). Rather than function as conventional CSs, contexts thus appear to have much in common with occasion setters. They modulate responding to a CS that is under the influence of inhibition or extinction, and this influence is independent of their direct associations with a US. In support of this conclusion, experimental tests for the interaction between contexts and occasion setters suggest that they act through a common mechanism (Honey & Watt 1999, Swartzentruber 1991).

In effect, research on contextual control and research on occasion setting has converged on the idea that CS-US associations may be hierarchically controlled by other cues. If this is correct, a further implication of the research on context is that this hierarchical function may be ubiquitous. Perhaps, for example, any association acquired after a CS has already entered into an association may involve hierarchical control by the context (Nelson 1997, Swartzentruber & Bouton 1992; cf. Harris et al 2000). Moreover, this control may be exerted by a variety of contextual cues, including interoceptive states created by drugs, moods, or even the passage

of time (Bouton 1993, Bouton et al 1999, Spear 1978). Spontaneous recovery after extinction, the fundamental phenomenon known since Pavlov (1927) but ignored by all current models of associative learning, can now be understood as the renewal effect that occurs with a change of temporal context (Bouton 1993, Brooks & Bouton 1993). These proposals are also of relevance to the catastrophic interference problem noted earlier (McCloskey & Cohen 1989). By the end of Phase 2, the original CS-US association may not be destroyed, but inhibited by a second association whose activation depends on the current context, whether it is provided by exteroceptive cues, interoceptive cues, or time.

We opened this section by showing how it is possible to explain the influence of the CS-US contingency on conditioning, by assuming that the context functions in the same way as any other stimulus. There are, however, alternative explanations for the contingency effect that postulate yet another role for the context (Gallistel & Gibbon 2000, Gibbon & Balsam 1981, Miller & Matzel 1988). Associations involving the context and a CS are assumed to progress independently of each other, and performance to the CS is determined by a comparison between the strength of the two. When the associative strength of the context is high, responding to the CS is commensurately weakened. A finding that is consistent with this comparator view is that nonreinforced exposure to the context after conditioning can increase responding to the CS (Matzel et al 1987). However, increasing the value of the context has no corresponding effect (Miller et al 1990), and comparator theory's account of related competition phenomena has also been challenged (Holland 1999; Rauhut et al 1999, 2000). Nonetheless, comparator theory has generated some new predictions that have been tentatively confirmed (e.g. Blaisdell et al 1998). Although comparator theory gives the context a novel role, this role is not unique to contexts and can be played by any CS.

In the end, although the Rescorla-Wagner model was correct in pointing toward the role of contextual cues in many learning paradigms, it is unlikely that contexts work solely through simple associations with the US. Like parallel research on occasion setting, research on contextual control suggests that a more complex associative structure may often be acquired in associative learning.

LEARNING ABOUT ABSENT STIMULI

The Rescorla-Wagner (1972) theory has been used principally to account for the associative changes that occur when the CS and US are physically present for conditioning. Several studies have shown, however, that it is not essential for a stimulus to be present for it to participate in associative learning. In a study of mediated conditioning, Holland (1981) used a tone to signal the delivery of distinctively flavored food pellets to rats. The tone was then presented by itself and followed by the injection of a toxin. Subsequent tests revealed that the attractiveness of the food pellets was reduced by this treatment. Such a finding implies

TABLE 1 The predictions made by different theories for conditioning with a CS and a US when they are either physically present (A1), or when a stimulus is present that has been paired with the CS or US (A2)

CS	US	Wagner	Holland	Dickinson & Burke
A1	A1	Excitatory	Excitatory	Excitatory
A1	A2	Inhibitory	Inhibitory	Inhibitory
A2	A1	No change	Excitatory	Inhibitory
A2	A2	No change	Inhibitory	Excitatory

that presenting the tone by itself activated a representation of food, which then entered into an association with the effects of the toxin (see also Ward-Robinson & Hall 1996). Holland (1983b) offered an explanation for this result in terms of a modified version of Wagner's (1981) theory, SOP. Recall that Wagner proposed that a representation of a stimulus can be in two states of activation: A1 or A2. If the representations of a CS and US are both in the A1 state, which will occur if the stimuli have just been presented, excitatory conditioning will take place. If one representation is in the A1 state and the other is in the A2 state, inhibitory conditioning will take place. If both representations are in the A2 state, no learning will occur. These principles, which are summarized in Table 1, are unable to explain mediated conditioning (Holland 1981). According to SOP, when the tone is presented by itself, the representation of food should be activated to the A2 state and the development of an excitatory association between food and illness should not be possible. Holland (1983b) therefore proposed that when the representations of the CS and US are, respectively, in the A2 and A1 states excitatory conditioning will occur in the same way as when both representations are in the A1 state (see Table 1).

A study of mediated extinction led Holland (1983b) to propose a further modification to Wagner's theory. Holland & Forbes (1982) gave rats a distinctively flavored food in the presence of a tone, prior to conditioned taste aversion training with the food. The aversion to food was then extinguished by repeatedly presenting the tone by itself. According to the original version of SOP, the tone by itself will activate a representation of food to the A2 state, which in turn, will activate the representation of illness to the A2 state. As Table 1 shows, the properties of food are predicted to be unaffected by this training. To explain his finding to the contrary, Holland (1983b) suggested that if representations of two stimuli are both in the A2 state then an inhibitory association will develop between them.

More recent findings indicate that the modification proposed by Holland (1983b) to Wagner's theory may apply in only restricted circumstances. Dwyer et al (1998; see also Harris & Westbrook 1998) studied mediated conditioning by capitalizing on the fact that animals will acquire a preference for a particular flavor if it has been paired with a sweet substance such as sucrose. Rats were allowed to drink a peppermint flavored solution in one context, and a mixture of almond and sucrose

in a different context. They were then allowed to drink almond in the first context. It was hoped that simultaneous exposure to the original context and to almond would activate representations of the events previously associated with them—peppermint and sucrose—and permit the development of an association between them. That is, this treatment was intended to enhance the preference for peppermint even though neither peppermint nor sucrose was presented. Subsequent test trials confirmed this prediction. In this experiment, therefore, allowing rats to drink almond in the original context can be assumed to activate A2 representations of both peppermint and sucrose, which according to the proposals of Holland (1983b), should have resulted in inhibitory rather than excitatory associations.

Dwyer et al (1998) explained their findings by referring to yet another modification to Wagner's theory (1981), which was originally proposed by Dickinson & Burke (1996). They proposed that excitatory associations will develop between representations in the same state (either both in A1 or both in A2) and that inhibitory associations will develop between representations in different states (one in A1 and the other in A2; see Table 1). These proposals can explain the findings of Dwyer et al (1998), but they are unable to explain the findings reported by Holland (1981) and Holland & Forbes (1982).

Additional support for the Dickinson & Burke (1996) version of SOP is provided by studies of retrospective reevaluation. In these experiments, an experience in the presence of a CS, which changes its associative properties, has the opposite effect on the properties of a stimulus that was paired with the CS in a prior conditioning task. For example, Kaufman & Bolles (1981) used a simultaneous noise-light compound to signal shock before the light was repeatedly presented without shock. Later test trials then revealed that the extinction treatment with the light enhanced conditioned responding to the noise (see also Miller et al 1992). According to Dickinson & Burke's proposals (1996), the extinction trials with the light will activate into the A2 state representations of the stimuli with which it was paired—shock and noise—and thus strengthen the excitatory connection between them.

For the moment, it is very difficult to draw any clear theoretical conclusions from the experiments considered in this section. Wagner's theoretical proposals (1981) provide an important step towards enhancing our understanding of the factors that govern the associability of stimuli, and of the associations that will be formed when a CS is actually present. However, it is not obvious how the theory can account for changes in the associative properties of a stimulus brought about through manipulations conducted in its absence. The results from different experiments are consistent with one or the other of two contradictory modifications to Wagner's theory, and the conditions that determine whether or not certain experimental manipulations will be effective remain to be specified. To complicate matters further, it is important to note that retrospective reevaluation is not always found with animals (Rescorla & Cunningham 1978, Speers et al 1980, Holland 1999, Rauhut et al 2000), and there are explanations for the phenomenon that do not appeal to any version of SOP (Miller & Matzel 1988). The theoretical analysis

of learning about absent stimuli is thus likely to progress slowly until the factors are identified that determine both the nature of this learning and whether or not it will take place. For a discussion of one factor, biological significance, that may influence this type of learning see Miller & Matute (1996).

APPLICATION OF THEORIES OF ANIMAL LEARNING TO HUMAN LEARNING

An important reason for studying associative learning in animals is the hope that once a set of theoretical principles has been identified, they will extend to learning in humans. There are two relatively recent areas of research in which theories of associative learning in animals are relevant to human learning: the judgment of causality, and categorization.

The Judgment of Causality

In a causal judgment task, participants are given hypothetical information about the relationship between a number of different possible causes and effects, often on a trial-by-trial basis. They may, for example, be told that an allergic reaction results from eating some food compounds, but not others (Van Hamme & Wasserman 1994). Participants are then asked to judge the degree to which a particular food causes the allergic reaction. According to contingency-based theories, people make this judgment on the basis of a statistical computation. They might calculate a value, Δp , which is the estimated probability of the outcome given the cause, minus the estimated probability of the outcome in the absence of the cause (Allan 1980). Alternative contingency-based methods for deriving causal judgments have been proposed by Cheng & Novick (1990) and Cheng (1997).

A different way of explaining how causal judgments are derived was proposed by Dickinson et al (1984), who suggested they develop on a trial-by-trial basis according to principles embodied in theories of associative learning. That is, causes are believed to be associated with effects in the same way as CSs become associated with USs. One justification for this belief is that effects such as blocking and conditioned inhibition can be reliably obtained in causal judgment tasks with humans (Baker et al 1993, Chapman & Robbins 1990, Dickinson et al 1984). A further justification is that when the effects of training have reached asymptote, the predictions made by the Rescorla-Wagner (1972) theory concerning a predictive cue are the same as those that can be derived by calculating Δp (Chapman & Robbins 1990).

At least four different lines of research have derived from the application of the theories of associative learning in animals to causal judgment by humans. First, there have been studies that have examined whether these theories do indeed provide an acceptable account of causal judgment by humans. Some researchers have claimed that fairly simple empirical phenomena are inconsistent with associative theory.

Cheng (1997), for instance, has cited a number of findings that she believes are more readily explained by a contingency-based account of causal judgment than an associative account—the Rescorla-Wagner (1972) theory. Interestingly, Lober & Shanks (2000) have pointed out that many of Cheng's (1997) arguments are valid only if it is assumed that the learning rate parameter, β , has the same value for reinforced and nonreinforced trials. Other researchers have reported findings that are more consistent with an associative- than a contingency-based account of causal judgment (e.g. López et al 1998, Vallée-Tourangeau et al 1998b). Another criticism of associative theory is that causal judgments are based on an understanding of how causes actually operate: Whereas two causes of an effect may compete with one another, two effects of one cause may not (Waldmann 2000, Waldmann & Holyoak 1992; but see Shanks & López 1996), yet associative theory has no way of distinguishing these cases because it treats them as identical associative learning problems.

Second, there have been studies that have evaluated the predictions made by different theories of associative learning in the context of human causal judgment. Thus, attempts have been made to compare predictions made by an elemental or a configural theory of associative learning. On some occasions these have lent clear support for configural theory (López et al 1998, Vallée-Tourangeau et al 1998a); on others, neither type of theory has provided a satisfactory explanation for the data. For example, Shanks et al (1998b) used a task that was similar in design to the study by Pearce & Wilson (1991) mentioned earlier. They found that presenting B+ trials after an A+/ABo discrimination had no effect on subsequent test trials with the AB compound. This demonstration of an immunity to the effects of retroactive interference contradicts predictions from both elemental and configural theories of associative learning. On a related issue, there have been attempts to explore whether prior training can encourage participants to adopt either an elemental or a configural strategy when they are confronted with a causal judgment task. Experiments by Williams (1995), Williams & Braker (1999), and Williams et al (1994) have lent considerable support to this proposal (but see Shanks et al 1998a).

Third, experiments have been directed at evaluating the relative contribution made by the acquisition of associations and rules to causal judgments. Thus, Shanks & Darby (1998) presented participants with trials in which individual stimuli, A or B, signaled nothing, and a compound CD signaled an outcome. These trials were intermixed among discriminations involving negative (E+/F+/EFo) or positive (Go/Ho/GH+) patterning. On testing, the participants indicated that they thought it more likely that AB than either C or D would be followed by the outcome. According to associative theories of learning, the opposite pattern of results should have been found. As a consequence, Shanks & Darby (1998) concluded that during the training stage subjects learned the rule "a compound and its elements predict opposite outcomes." Not only would the use of this rule facilitate the acquisition of the discriminations, but it would also account for the results of the test trials (Lachnit & Kimmel 1993).

Finally, causal judgment experiments have been used to study retrospective reevaluation (see previous section) in humans (Chapman 1991, Dickinson & Burke 1996, Shanks 1985, Wasserman & Berglan 1998). Participants may be first told that a meal of two different foods, AB, is followed by an allergic reaction. Subsequently being told that B alone produces the same reaction is then generally found to reduce the degree to which A is seen a cause of the allergic reaction. Such retrospective reevaluation of A is hard to explain with many associative theories (e.g. Rescorla & Wagner 1972), but it is easy to explain by contingency-based theories of causal judgment because they do not take account of the order in which trials are presented. Although it might therefore seem that retrospective reevaluation is more consistent with contingency-based than associative theories of causal judgment, recent theoretical developments caution against such a conclusion. Retrospective reevaluation can be explained by Miller & Matzel's (1988) theory, as well as by the modifications to the Rescorla-Wagner (1972) theory proposed by Van Hamme & Wasserman (1994) and to SOP proposed by Dickinson & Burke (1996). Indeed, Aitken et al (2000) argue that the modifications to SOP provide a better account of causal judgment than contingency based theories.

Categorization

Theories of associative learning in animals have had relatively little impact on the study of categorization in humans (but see Gluck & Bower 1988). Nonetheless, there is a close correspondence between some of these theories and certain theories of categorization in humans. The basic idea is that features of exemplars become associated with categories in the same way that CSs are associated with USs. Thus, the Rescorla-Wagner (1972) theory is formally equivalent to the model of categorization proposed by Gluck & Bower (1988). Furthermore, because the delta rule, which lies at the heart of a number of connectionist theories of learning and categorization (Rumelhart et al 1988), is similar to the error-correction rule used by Rescorla & Wagner (1972), it can be shown that the Rescorla-Wagner theory is closely related to these theories (Sutton & Barto 1981). There are also close links between the configural theory of conditioning proposed by Pearce (1987, 1994) and the exemplar-based theory of categorization proposed by Kruschke (1992). Although the relative merits of these different classes of theories of human learning are still under scrutiny, the fact that they correspond closely to theories of learning in animals strongly encourages the belief that there is much in common between the fundamental mechanisms of associative learning in animals and humans.

CONCLUDING COMMENTS

Theories of associative learning provide parsimonious, formal explanations for findings from both Pavlovian and instrumental conditioning. They have made steady progress over the years. However, we may note at least two gaps that still

remain in our current understanding. First, although the theories now provide a reasonably sophisticated understanding of the processes involved in association formation, they say relatively little about how the association is manifested in the performance of behaving animals. We must therefore look to other theories to understand the behavioral output of the processes reviewed here (Domjan 1998, Fanselow 1994, Timberlake & Silva 1995). Second, recent research has been increasingly directed at understanding the role of timing in conditioning (Denniston et al 1998, Gallistel 1990, Gibbon 1977). Gallistel & Gibbon (2000) have argued that timing plays a fundamental role in conditioning by determining not only when an animal responds, but also whether or not it responds during both acquisition and extinction. They further argue that an adequate account of timing in conditioning lies beyond the scope of associative learning theory. Instead they favor a radically different theory that assumes that the duration and rate of events, rather than the conditioning trial, is the psychological "primitive" from which all conditioning phenomena are ultimately derived. Associative learning theory is likely to rise to this, and other, challenges by finding new, hopefully elegant, ways of accommodating problematic phenomena within existing theoretical frameworks.

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