Pavlovian Conditioning

It's Not What You Think It Is

Robert A. Rescorla *University of Pennsylvania*

ABSTRACT: Current thinking about Pavlovian conditioning differs substantially from that of 20 years ago. Yet the changes that have taken place remain poorly appreciated by psychologists generally. Traditional descriptions of conditioning as the acquired ability of one stimulus to evoke the original response to another because of their pairing are shown to be inadequate. They fail to characterize adequately the circumstances producing learning, the content of that learning, or the manner in which that learning influences performance. Instead, conditioning is now described as the learning of relations among events so as to allow the organism to represent its environment. Within this framework, the study of Pavlovian conditioning continues to be an intellectually active area, full of new discoveries and information relevant to other areas of psychology.

Pavlovian conditioning is one of the oldest and most systematically studied phenomena in psychology. Outside of psychology, it is one of our best known findings. But at the same time, within psychology it is badly misunderstood and misrepresented. In the last 20 years, knowledge of the associative processes underlying Pavlovian conditioning has expanded dramatically. The result is that modern thinking about conditioning is completely different from the views psychologists held 20 years ago. Unfortunately, these changes are very poorly appreciated by psychologists at large. The last time many psychologists read anything about Pavlovian conditioning was before these changes took place. Even those more recently educated often received that education from textbooks and instructors that had largely ignored the dramatic conceptual changes that had taken place. The result is that many think of Pavlovian conditioning as an obsolete technical field that is intellectually stagnant.

My intention in this article is to show that this view is incorrect. First, I will review some of the changes that have occurred in Pavlovian conditioning in order to give the flavor of its contemporary form. I will argue that it is an intellectually challenging field, in which substantial and exciting progress has been made. Second, I will argue that conditioning continues to have a central place in psychology generally. I will describe how it touches on and informs several related fields that are currently more in vogue.

To begin the discussion, consider how conditioning was described 20 years ago, when those in my generation were students. One popular introductory text put it thus:

> The essential operation in conditioning is a *pairing* of two stimuli. One, initially neutral in that it elicits no response, is called the *conditioned stimulus* (*CS*); the other, which is one that consistently elicits a response, is called the *unconditioned stimulus* (*US*). The response elicited by the unconditioned stimulus is the *unconditioned response* (*UR*). As a result of the pairing of the conditioned stimulus (CS) and the unconditioned stimulus (US), the previously neutral conditioned stimulus comes to elicit the response. Then it is called the *conditioned response* (*CR*). (Morgan & King, 1966, pp. 79–80)

This description is typical of those found in both introductory and advanced textbooks 20 years ago.

Unfortunately, it is also typical of what one finds in textbooks today. One popular introductory text published in 1987 describes conditioning in this way: "The originally neutral conditioned stimulus, through repeated pairing with the unconditioned one, acquires the response originally given to the unconditioned stimulus" (Atkinson, Atkinson, Smith, & Hilgard, 1987, p. 658). Students are exposed to similar descriptions in textbooks specializing in allied fields of psychology. In a cognitive textbook, one reads,

> We start out by taking an unconditioned stimulus (UCS) that produces the desired response without training. . . . We pair the UCS with a conditioned stimulus (CS). . . . This procedure, when repeated several times . . . will ultimately result in the occurrence of the response following the CS alone. (Klatsky, 1980, p. 281)

A widely used developmental text agrees, calling conditioning a "form of learning in which a neutral stimulus, when paired repeatedly with an unconditioned stimulus, eventually comes to evoke the original response" (Gardner, 1982, p. 594). Similarly, a best-selling textbook of abnormal psychology describes a conditioned stimulus as "a stimulus that, because of its having been paired with another stimulus (unconditioned stimulus) that naturally provokes an unconditioned response, is eventually able to evoke that response" (Rosenhan & Seligman, 1984, p. 669).

Of course, textbook descriptions vary widely in their precision and sophistication, but these citations represent a common view. Indeed, these quotations will certainly sound so familiar that many readers may wonder what is wrong with them. I want to suggest that the answer is "almost everything." These descriptions make assertions about what I take to be the primary issues to be addressed in the study of any learning process: What are the circumstances that produce learning? What is the content

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of the learning? How does that learning affect the behavior of the organism? But they are mistaken or misleading in virtually every assertion they make about each of these. These descriptions in fact capture almost nothing of modern data and theory in Pavlovian conditioning.

I want to illustrate this claim using some data collected in my own laboratory over the years, but first let me make an orienting comment. Descriptions of conditioning, such as those just cited, come from a long and honorable tradition in physiology, the reflex tradition in which Pavlov worked and within which many early behaviorists thought. This tradition sees conditioning as a kind of low-level mechanical process in which the control over a response is passed from one stimulus to another. Much modern thinking about conditioning instead derives largely from the associative tradition originating in philosophy. It sees conditioning as the learning that results from exposure to relations among events in the environment. Such learning is a primary means by which the organism represents the structure of its world. Consequently, Pavlovian conditioning must have considerable richness, both in the relations it represents and in the ways its representation influences behavior, a richness that was not envisioned within the reflex tradition.

Let me now turn to illustrating the difference that this alternative view makes for each of three issues: the circumstances producing learning, the content of learning, and the effects of learning on behavior.

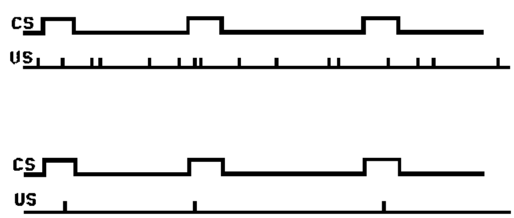
Circumstances Producing Pavlovian Conditioning

Each of the descriptions given earlier cites one major circumstance as responsible for producing Pavlovian conditioning, the pairing or contiguity of two events. To be sure, contiguity remains a central concept, but a modern view of conditioning as the learning of relations sees contiguity as neither necessary nor sufficient. Rather, that view emphasizes the information that one stimulus gives about another. We now know that arranging for two well-processed events to be contiguous need not produce an association between them; nor does the failure to arrange contiguity preclude associative learning.

The insufficiency of contiguity for producing Pavlovian conditioning can be illustrated by results that have been available for almost 20 years (e.g., Rescorla, 1968) but that have apparently failed to be integrated into the view of conditioning held by many psychologists. Consider a learning situation in which a rat is exposed to two prominent events, a tone CS that occurs for two-minute periods and a brief, mild electric shock US applied to a grid on which the animal is standing. Suppose that those two events are uncorrelated in time, such that the tone provides no information about the shock. That relation is schematized in the top of Figure 1. Also schematized in that figure is a variation on that treatment in which only those USs scheduled to occur during the tone are actually applied to the animal. The point to notice about those two treatments is that they share the same contiguity of the tone with the US, but they differ in the amount of information that the tone gives about the US. In the first treatment, the shock is equally likely whether or not the tone is present, and so the tone provides no information; in the second treatment, the shock only occurs during the tone, and so the tone is quite informative about shock occurrence. It turns out that in many conditioning situations learning is determined not by what these treatments share but rather by how they differ. The second group will develop an association between the CS and US, but the first will fail to do so. In effect, conditioning is sensitive to the base rate of US occurrence against which a CS/US contiguity takes place.

Indeed, systematic experiments show that in many situations the amount of conditioning is exquisitely attuned to variations in the base rate of the US. An early illustration of that point is shown in Figure 2, which plots asymptotic levels of fear conditioning (measured by the ability of the CS to interfere with ongoing behavior) as a function of the likelihood of the US during the CS. The parameter in the figure is the base-rate likelihood of the US in the absence of the CS. Each curve shows that conditioning is indeed an increasing function of the likelihood of the shock during the tone. For instance, in the frequently studied case in which the shock likelihood is zero in the absence of the CS, then conditioning is greater the greater the probability of the shock during the tone. This is not a surprising result. What is more interesting is the effect of the base rate of US occurrence in the absence of the CS. At any given likelihood of shock during the CS, conditioning is an inverse function of the base rate. When the CS/US contiguity is held constant, conditioning changes from excellent to negligible simply by increasing the shock base rate. Indeed, when the likelihood of a US is the same in the presence and absence of the CS (as is true of the initial point on each function), there is little evidence of conditioning at all. One description of these results is that conditioning depends not on the contiguity

Figure 1
Schematic of Two Conditioned Stimulus/Unconditioned Stimulus (CS/US) Relations That Share the Same Contiguity but Differ in the Information the CS Gives About the US



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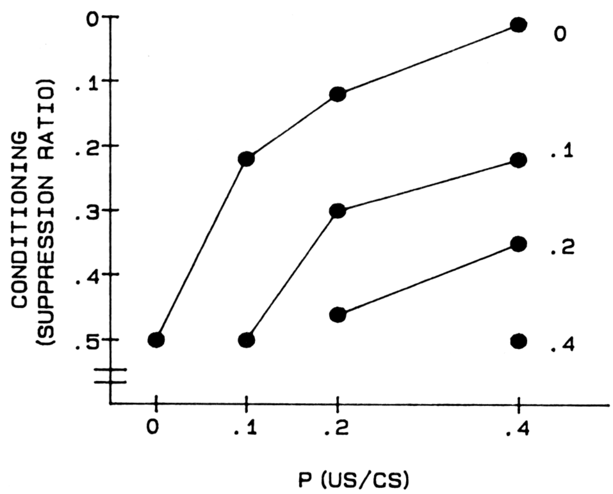
Correspondence concerning this article should be addressed to Robert A. Rescorla, Department of Psychology, University of Pennsylvania, 3815 Walnut St., Philadelphia, PA, 19104.

Figure 2
Dependence of Conditioning on Both the Likelihood of the US During the CS and the Base Rate of US Occurrence in the Absence of the CS



Note. Adapted from "Probability of Shock in the Presence and Absence of CS in Fear Conditioning" by R. A. Rescorla, 1968, *Journal of Comparative and Physiological Psychology, 66,* p. 4. Copyright 1968 by the American Psychological Association. Reprinted by permission. Asymptotic fear conditioning is plotted as a function of shock likelihood during the conditioned stimulus (CS). The parameter is the shock likelihood in the absence of the CS. When the CS/US contiguity [P(US/CS)] is held constant, conditioning varies from substantial to negligible as a function of the US (unconditioned stimulus) base rate. Conditioning is indexed by a ratio comparing responding during the CS with the ongoing response rate. With that ratio, 0.5 indicates no conditioning and 0 indicates excellent conditioning.

between the CS and the US but rather on the information that the CS provides about the US. These are early data, but the basic results have been observed repeatedly in a variety of conditioning preparations. They strongly suggest that simple contiguity of CS and US fails to capture the relation required to produce an association.

The same conclusion is suggested by various other modern conditioning phenomena, such as the Kamin (1968) blocking effect. That effect has had a profound impact on contemporary thinking about Pavlovian conditioning, yet it is unknown to many psychologists. In a simple blocking experiment, two groups of animals receive a compound stimulus (such as a light and tone) signaling a US. Eventually both groups will be tested for their conditioning of one stimulus, say the tone. However, one of the groups has a history of the light alone signaling the US, whereas the other group lacks that history. Notice that the two groups share the same contiguous occurrence of the US with the light/tone compound, but they differ in that for one the prior training of the light makes the tone redundant. The result of interest is that the tone becomes well conditioned in the first group but poorly conditioned in the group with light pretraining. Conditioning is not governed by the contiguity that the groups share but rather by the informational relation on which they differ. Again, simple contiguity of two events fails to capture the results; rather, information seems important. This is a result that has been widely repeated in many conditioning situations.

These two classic experiments illustrate that contiguity is not sufficient to produce Pavlovian conditioning. But neither is contiguity necessary to produce Pavlovian associations. This can be illustrated in a variety of ways, but a simple one makes reference to the treatments in Figure 1. Consider a variation on the first treatment in which, instead of omitting all of the shocks in the absence of the tone, we omit all those in its presence. This variation takes away all of the CS/US contiguities while maintaining a high base rate of US occurrence. Under these circumstances, the organism does not simply fail to learn; rather, it learns that there is a negative relation between the tone and the US. In the jargon of the field, the tone becomes a conditioned inhibitor. Again, this outcome is not intuitively surprising, but neither is it well accommodated by the description of conditioning in which the main circumstance producing learning is contiguity. Yet conditioned inhibition is a major part of modern thinking about Pavlovian conditioning. No theory of conditioning would be considered adequate if it failed to explain a wide variety of inhibitory phenomena (cf. Miller & Spear, 1985).

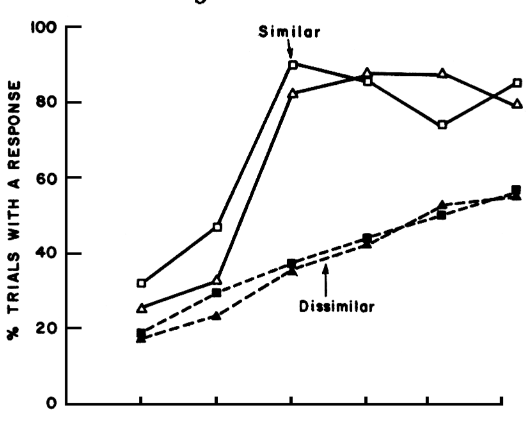
These kinds of results clearly suggest that the simple pairing of two events cannot be taken as fundamental to the description of Pavlovian conditioning. Instead, they encourage the prevalent modern view that conditioning involves the learning of relations among events. It provides the animal with a much richer representation of the environment than a reflex tradition would ever have suggested. Of course, one cannot leave the analysis at this level; rather, one needs to provide theories of how these relations are coded by the organism. Such theories are now available, several of which are stated in sufficient quantitative detail to be taken seriously as useful accounts (e.g., Mackintosh, 1975; Pearce & Hall, 1980; Rescorla & Wagner, 1972). These theories emphasize the importance of a discrepancy between the actual state of the world and the organism's representation of that state. They see learning as a process by which the two are brought into line. In effect, they offer a sophisticated reformulation of the notion of contiguity. A useful shorthand is that organisms adjust their Pavlovian associations only when they are "surprised." This is not the place to describe these theories in detail, but they do an excellent job with phenomena like those described in Figure 2.

The importance of relations can be seen in yet another way. It is not only temporal and logical relations among events that are important to conditioning. Conditioning is also sensitive to relations involving the properties of the events themselves. There is a kind of abstractness with which the descriptions of conditioning are often stated, an abstractness that is characteristic of a field seeking general principles. These descriptions suggest that conditioning occurs whenever one arranges a temporal relation among the events, regardless of the other properties of the events. The claim in essence is that the animal comes to conditioning with no preconceptions about the structure of the world, ready to accommodate itself to any world that it faces. Pavlovian conditioning has, of course, served as one of the pillars for radical empiricism. But in modern times it has become clear that this pillar itself is partly built on the existing structure in the organism. Not all stimuli are equally associable; instead, a stimulus may be easier to associate with some signals rather than others. The most well-known demonstration of this, of course, is Garcia and Koelling's (1966) seminal work on the cue-to-consequence effect. They found that an internal distress was easier to associate with a gustatory rather than an auditory–visual stimulus, whereas a peripherally administered pain was more readily associated with the auditory–visual rather than the gustatory stimulus.

But this work is not alone in identifying instances of preferential learning among stimuli bearing qualitative relations to each other. For instance, spatial relationship, a variable important to philosophical associationism but neglected by the reflex tradition, is now known to affect Pavlovian associations (e.g., Rescorla, 1980). Similarly, recent work shows that perceptual relations among events, such as similarity and the part–whole relation, also are important determinants of conditioning.

Figure 3 shows an example of how one perceptual relation (part to whole) affects the results of Pavlovian conditioning. Those results come from an autoshaping experiment in pigeons. Autoshaping is one of the most popular modern Pavlovian preparations, so it is worth mentioning in its own right. In that preparation, birds are exposed to a response-independent signaling relation between an illuminated disc (say, a red square or a red triangle) and food. As the birds learn that relation, they come to peck the disc. That result is worth analysis of its own, but for the present we will simply take it as an index that the birds have associated the red square with food. More important for our present purposes, they will peck not only the red square but also localized stimuli that in turn signal the red square (producing so-called second-order conditioning). Figure 3 shows the development of pecking at two stimuli, colorless outlines of a square and a triangle, when they signal a red square and a red triangle. For the animals having a *similar* relation, each colored figure was signaled by the same-form achromatic figure; each whole was signaled by one of its parts. For the animals having a *dissimilar* relation, the colored figures were also signaled by the achromatic figures except that the forms were mismatched so as to destroy the part–whole relation. It is clear that conditioning proceeded more rapidly in animals who had the part–whole relation. That is, a perceptual relation influenced the formation of an association. This is a particularly interesting perceptual relation because in the natural environment partial information about an object frequently serves as a signal of the entire object. Apparently, Pavlovian conditioning is especially sensitive to that fact.

Figure 3
Effect of a Part–Whole Relation on Pavlovian Conditioning



Note. From *Pavlovian Second-Order Conditioning: Studies in Associative Learning* (p. 49) by R. A. Rescorla, 1980, Hillsdale, NJ: Erlbaum. Copyright 1980 by Lawrence Erlbaum Associates. Reprinted by permission. Responding is shown to two second-order stimuli, an outline triangle and outline square, that signaled a colored triangle or a colored square. In the *similar* group, each outline form signaled a colored form of the same shape; in the *dissimilar* group, each signaled a colored form of a different shape.

One final comment needs to be made about the circumstances that produce conditioning. It is a commonly held belief that Pavlovian conditioning is a slow process by which organisms learn only if stimulus relations are laboriously repeated over and over again. Several of the descriptions cited earlier acknowledge this belief by using such terms as *repeatedly* and *eventually.* However, this view is not well supported by modern data. Although conditioning can sometimes be slow, in fact most modern conditioning preparations routinely show rapid learning. One-trial learning is not confined to flavor-aversion learning, and learning in five or six trials is common. In fact, the data displayed in Figure 3 are a good example of learning that is excellent after eight trials. Notice that those data were obtained in a second-order conditioning paradigm, a procedure that itself has an undeserved reputation for being weak and transient (see Rescorla, 1980).

The picture that emerges from this discussion of the circumstances that produce conditioning is quite different from that given by the classical descriptions. Pavlovian conditioning is not a stupid process by which the organism willy-nilly forms associations between any two stimuli that happen to co-occur. Rather, the organism is better seen as an information seeker using logical and perceptual relations among events, along with its own preconceptions, to form a sophisticated representation of its world. Indeed, in teaching undergraduates, I favor an analogy between animals showing Pavlovian conditioning and scientists identifying the cause of a phenomenon. If one thinks of Pavlovian conditioning as developing between a CS and a US under just those circumstances that would lead a scientist to conclude that the CS causes the US, one has a surprisingly successful heuristic for remembering the facts of what it takes to produce Pavlovian associative learning (see Dickinson, 1980; Mackintosh, 1983).

Content of Pavlovian Conditioning: What Is Learned

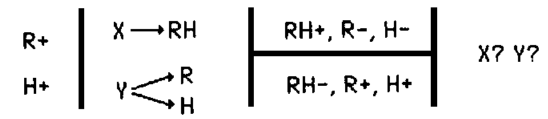
The descriptions of conditioning given earlier imply a highly restricted content in which a single neutral stimulus becomes associated with one that evokes a response. But modern Pavlovian thinking suggests a picture that is richer in two ways.

First, it is clear that in any Pavlovian experiment the animal learns about many different stimuli. Associations are formed not just between the primary events psychologists present, the CS and US. For instance, each of those events also becomes associated with the context in which they are presented (e.g., Balsam & Tomie, 1985). Such associations are one way that organisms use Pavlovian conditioning to code spatial information. Moreover, associations form not only between events but also within each of the events that the traditional description identifies (e.g., Rescorla & Durlach, 1981). Indeed, considerable effort is going into analyzing the latter learning because within-event associations may be one way that the organism represents individual events. Moreover, many examples of Pavlovian associations involve stimuli that do not evoke an original response. Pavlovian conditioning also encodes the relations among relatively innocuous events. So, modern experimentation supports the proposition that the organism concurrently forms a broad range of associations among a wide variety of stimuli. Moreover, quite powerful procedures have been developed to expose the existence of these associations and to carry out an analysis of their properties.

Second, modern Pavlovian thinking does not envision all of this learning taking place among simple pairs of elements all treated at the same level of analysis by the organism. Rather, as the British associationists claimed years ago, there is good reason to believe that there is a hierarchical organization in which associations among some pairs of items yield new entities that themselves can enter into further associations.

One illustration comes from a recent second-order autoshaping experiment conducted in my laboratory, the experimental design of which is shown in Figure 4. In this experiment, one stimulus (*X*) signaled the occurrence of a compound stimulus composed of a keylight that was red (R) on one half and had horizontal stripes (H) on the other half. The birds were interested in that fact because R and H each had a separate history of signaling the occurrence of food. Previous experiments had demonstrated that the birds would come to peck *X* as a result of its second-order conditioning by the RH compound. The question of interest was what would be the associative structure that supported that pecking. One possibility is that the bird would form two pairwise associations, learning the individual associations of *X* with R and with H. But a more interesting possibility is that the organism would form a representation of the RH event (perhaps using the association we know forms between R and H in such settings) and then use that representation as an element to associate with *X*. Either associative structure would cause the bird to show conditioning to *X*, but the former solution involves two parallel associative connections, whereas the latter involves a hierarchical organization.

Figure 4
Design of an Experiment Demonstrating Hierarchical Organization

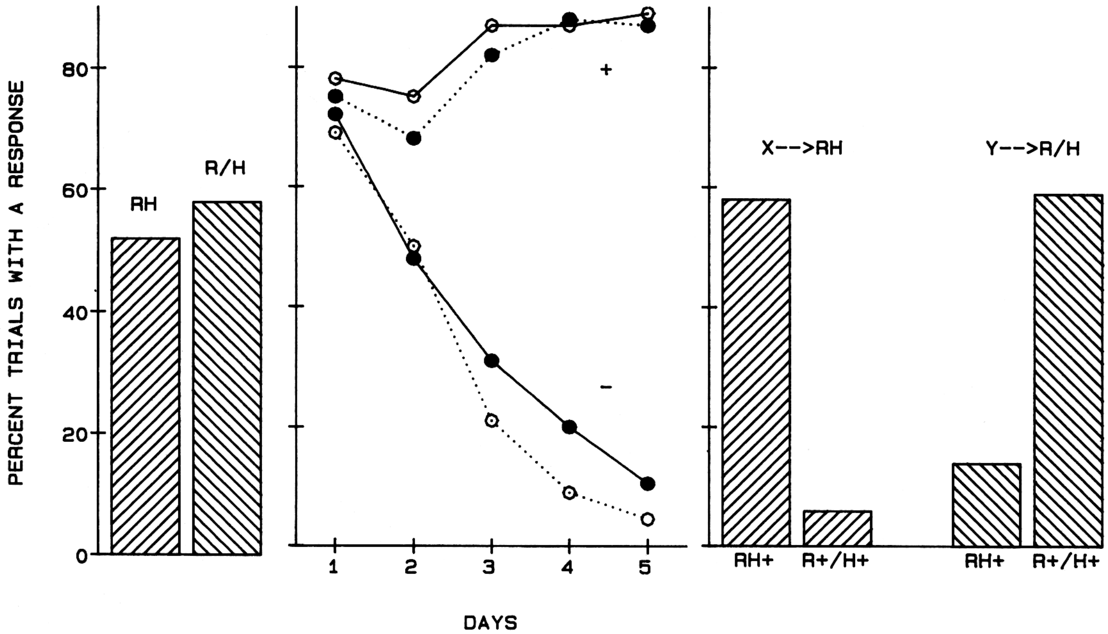


Note. Birds received first-order Pavlovian conditioning of two keylights (R and H) with a food (+) unconditioned stimulus (US). Then one second-order stimulus (*X*) signaled the RH compound, whereas another (*Y*) signaled the elements. Then the birds received one of two conditional discriminations between the RH compound and its elements and were tested for the response to *X* and *Y*. The physical identities of the *X* and *Y* stimuli were counterbalanced as a blue keylight and a black *X* on a white background.

The technology of modern Pavlovian conditioning provides a way to separate these two alternatives. In many conditioning preparations, responding to a signal tracks the current state of its associate (e.g., Rescorla, 1980). If the value of a reinforcer is changed after conditioning has been completed, subsequent responding to its associated CSs will also change accordingly. This fact can be used to decide with which stimulus *X* has become associated. In this instance, we deliberately gave the RH compound and its elements different values. For some animals, we extinguished the separately presented R and H elements but reinforced the RH compound; for others, we did the converse. Then we tested responding to *X*. If the animal has only separate associations of *X* with the R and H elements, responding to *X* should track the value of those elements, but if *X* has an association with RH, responding should track the compound's value rather than that of the R and H elements. In order to compare the results from *X* with those from an associative structure that we know to represent simple pairwise associations, we also used R and H to condition another stimulus (*Y*). Like *X*, *Y* was followed by R and H, but unlike *X*, *Y* received R and H on separate trials, thereby ensuring its having separate associations with those elements. As a result, responding to *Y* should track the current value of the R and H elements, not that of the RH compound.

The results of various stages of this experiment are shown in Figure 5. The first panel shows the level of responding to *X* and *Y* at the end of their second-order conditioning by the RH compound and the R and H elements. Those treatments produced similar levels of conditioning. On that basis alone, one cannot identify any differences in the associations of *X* and *Y*. The middle panel shows the course of the discriminations between RH and its elements. The birds could readily code a compound and its elements differentially, a result of some interest in itself. But the data of most interest are those shown in the final panel, from the testing of the second-order *X* and *Y* stimuli. Consider first the results from *Y*,

Figure 5
Results of an Experiment Demonstrating Hierarchical Organization



Note. The left panel shows asymptotic second-order conditioning of *X* and *Y* by the RH compound and the R and H elements, respectively. The middle panel shows a conditional discrimination of the form RH+, R−, H− (solid symbols) or RH−, R+, H+ (open symbols). The right panel shows responding to *X* and *Y* as a function of the most recent treatment of the RH compound and its elements. In both cases, responding to *X* and *Y* tracked the current value of the stimulus that it had signaled.

which had signaled R and H separately. Responding to that stimulus tracked the value of the individual R and H elements, not the value of the RH compound. Under those conditions, individual associations are indeed formed. Quite different are the results of testing *X*, the stimulus that had signaled the RH compound. Responding to that stimulus tracked the current value of the RH compound rather than the value of its elements. Clearly, the animals had not simply coded the RH compound in terms of parallel associations with its elements. Rather, they had engaged in some more hierarchical structuring of the situation, forming a representation of the compound and using it as an associate. This is the kind of hierarchical organization envisioned by the British associationists; it is extremely important because it may provide a means for an associative theory to build complex performances by bootstrapping based on elementary mechanisms. Such hierarchical structures are often discussed in various learning literatures, but they turn out to be very difficult to document definitively. One demonstration, however, can be given within the framework of Pavlovian conditioning.

Another illustration of such a hierarchical structure comes from recent demonstrations of a phenomenon variously called "occasion-setting" and "facilitation" (Holland, 1983; Rescorla, 1985). That phenomenon arises in situations in which a Pavlovian stimulus is deliberately arranged to signal not another stimulus but rather a relation between two other stimuli. Under proper conditions, such learning readily develops. Moreover, it can be relatively independent of the learning of separate associations to the elements. For instance, a stimulus that signals a positive relation between two other stimuli can simultaneously have either excitatory or inhibitory associations with the elements themselves.

Several laboratories are currently actively engaged in analyzing this kind of hierarchical relation. Their findings have important general implications for our understanding of Pavlovian conditioning. They suggest that associations may play a modulatory, rather than an elicitive, role. And they are changing the way we think about excitatory and inhibitory associations. Moreover, thinking about this modulatory role is beginning to be brought to bear on the analysis of stimulus control in instrumental learning.

Modern thinking about Pavlovian conditioning views associations as basic, but those associations are formed among representations of multiple events. Moreover, those representations themselves are often complex and include relations generated by other associations. Pavlovian conditioning does not consist simply of learning relations between a neutral event and a valuable event. Many different associations are formed, and the resulting content of learning allows a rich representation of the world.

Influences on Behavior

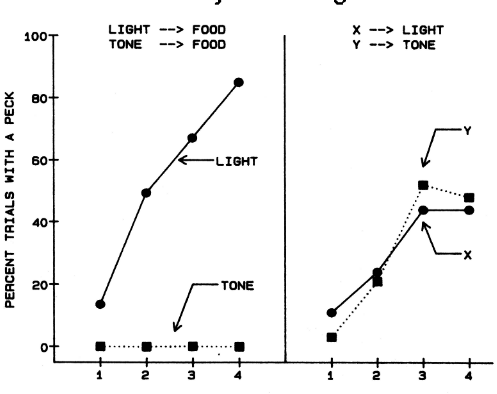
The descriptions quoted earlier contain a highly restricted view of how conditioning affects behavior. They envision only one way in which performance is generated: The CS becomes capable of evoking the response originally evoked by the US. However, there are very few students of conditioning who would care to defend that claim. There are three reasons why I believe it should be rejected.

First, many of the standard conditioning preparations simply do not show this feature. Consider, for instance, conditioned suppression situations such as those used to collect the data shown in Figure 2. The response to the shock US is abruptly increased activity, whereas the response to a tone signaling that shock is dramatically reduced activity.

Second, there is an important, but poorly appreciated, fact about conditioning that makes nonsense out of any claim that a signal simply acquires the ability to evoke the response to the US: The response observed to a CS often depends not only on the US but also on the perceptual properties of the CS itself. Two different signals of the same US may evoke quite different responses. For instance, for rat subjects a diffuse tone that signals a shock US results in immobility, but a localized prod signaling shock results in attempts to hide the prod from view by covering it with any available material (e.g., Pinel & Treit, 1979). Similarly, different CSs signaling food to a pigeon come to produce quite different response forms. As noted above, a localized visual signal of food evokes directed pecking. However, a diffuse auditory signal of that same food does not evoke pecking but rather enhances general activity. Figure 6 shows a relevant illustration from a recent experiment in our laboratory. The left-hand panel of that figure shows the results of giving the same birds separate keylight and auditory signals for food. It is clear that the birds came to peck during the keylight but not during the tone. But the absence of pecking does not result from a failure of learning about the tone. Direct observation of the bird shows that the tone produces enhanced general activity. Moreover, the right-hand panel of Figure 6 suggests that although the tone and light evoke different responses, the bird has in some sense learned the same thing about the two stimuli. That panel shows the results of a second stage of the experiment in which the light and the tone were each signaled by another keylight (X and Y). Both the tone and the light served as excellent reinforcers, thereby displaying that they had become associated with food. There are two points to note from this demonstration: First, the form of the conditioned response varies from CS to CS, and so it cannot always be like the response to the US. Second, sometimes we have difficulty seeing any evidence of learning if we simply look at the responses elicited by the CS; rather, other measures, such as the ability to serve as a reinforcer, can often provide better evidence of learning.

Figure 6

Dependence of the Form of the Conditioned Response on the Identity of the Signal

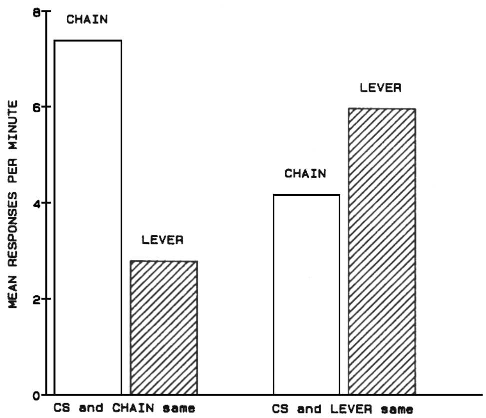


Note. The left panel shows keypecking in birds for whom both a localized keylight and a diffuse tone signaled food. The right panel shows keypecking to two other localized keylights (X and Y) that signaled the light and tone, respectively. The physical identities of X and Y were counterbalanced as red and green.

The third reason to reject the classical notion of how conditioning affects performance is that there is a sense in which the response one sees to a Pavlovian CS can be arbitrarily selected by the experimenter. That is possible because one important feature of Pavlovian conditioning is its involvement in goal-directed instrumental performance. It has been known for years that Pavlovian conditioning makes important contributions to the control of emotions and motivations. Twenty years ago, one of my most respected professors, Frank Irwin, asked me how I could be interested in Pavlovian conditioning, a process that he characterized as being "all spit and twitches" and of little general psychological interest. But it is important to understand that Irwin's characterization was wrong. Conditioning is intimately involved in the control of central psychological processes, such as emotions and motivations. In fact, two-process theories of instrumental performance are built on that proposition (e.g., Mowrer, 1947; Rescorla & Solomon, 1967; Trapold & Overmier, 1972).

In our laboratory, we routinely exploit the effect on instrumental behavior to detect the presence of a Pavlovian association. Figure 7 shows the results of one recent experiment conducted in collaboration with Ruth Colwill. These data come from rat subjects that are making an instrumental choice response, pulling a chain for a pellet or pressing a lever for liquid sucrose. While they were engaging in those performances, we presented a CS that had been made a Pavlovian signal either of food or of sucrose. The result of interest is that presentation of the Pavlovian CS biased the results of the instrumental performance. When the CS signaled the same reinforcer as did the chain pull, it enhanced chain pulling relative to lever pressing; on the other hand, when the CS shared the same reinforcer with the lever press, it enhanced lever pressing (cf. Kruse, Overmier, Konz, & Rokke, 1983). The point is that we can modulate an arbitrarily selected response (chain pulling and lever pressing) by the presentation of a Pavlovian signal. The same Pavlovian conditioning can show up in a broad range of responses depending on the context in which it is assessed. These results are of interest for what they tell us about the animal's

Figure 7
Exhibition of Pavlovian Conditioning in the Control of Instrumental Behavior



Note. Responding is shown during the presentation of a Pavlovian conditioned stimulus (CS) that signaled the same reinforcer as that earned either by a chain pull or a lever press.

knowledge about the consequences of its instrumental responding (see Colwill & Rescorla, 1986), but in the present context they make the point that conditioning can show up in arbitrarily selected behaviors, not just in the response the US evoked.

The implication is that describing Pavlovian conditioning as the endowing of a CS with the ability to evoke the same response as the US is a wholly inadequate characterization. Pavlovian conditioning is not the shifting of a response from one stimulus to another. Instead, conditioning involves the learning of relations among events that are complexly represented, a learning that can be exhibited in various ways. We are badly in need of an adequate theory of performance in Pavlovian conditioning, but the classical notion of a new stimulus taking on the ability to evoke an old response clearly will not do.

Return for a moment to the definitions of conditioning with which we began. They emphasized repeated pairing between two stimuli, one neutral and one valuable, with the result that the neutral one comes to evoke the response of the valuable one. But we have seen that pairing is not central, that all sorts of stimuli become associated in a manner that goes beyond simple dyadic relations, and that the Pavlovian associations influence behavior in many ways other than by the transferring of a response.

Finally, it is worth noting that these changes in our views of Pavlovian conditioning have been accompanied and encouraged by changes in the laboratory preparations used for its study. Many of the early observations in conditioning were made using the salivary preparation, often by Pavlov (1927) himself. But no contemporary American laboratory makes extensive use of that technique. As can be seen from the preceding discussion, modern studies of conditioning use a much more diverse set of procedures, involving a range of signals, consequences, and behavioral measures, in various species. The flexibility of contemporary thinking is partly an adaptation to that diversity.

The Place of Pavlovian Conditioning in Psychology

It is worth making some comments about the role of Pavlovian conditioning in psychology in general because that has also changed. It is important to realize that those who study this elementary learning process are not nearly as imperialistic as the animal learning psychologists of the 1940s and 1950s. In those days, conditioning was more than a learning process. It was the centerpiece for a set of theories intended to explain all behavior. More than that, it represented a way of doing science. Because conditioning came to psychology at a time when psychologists were working out scientific ways of studying behavior, it became bound up with considerable philosophical baggage. It stood not only for an explanation of psychological phenomena but also for a way of doing psychology altogether. One can still see some of the aftereffects of this heritage in the conservative style of introducing new theoretical concepts and in the commitment to elementarism. But Pavlovian conditioning has largely shed its philosophical role. Those who study conditioning have little interest in recapturing all of psychology in the name of behaviorism. What then is the role of Pavlovian conditioning in psychology? I see three kinds of contributions that it continues to make.

First, it continues to be a sample learning process that admits of careful detailed analysis. It is, of course, only one of a possibly quite large number of learning processes. Few would claim that all improvements from experience are based on a single process. However, Pavlovian conditioning is an important learning process for which the analysis is proceeding apace. As I hope my previous comments have illustrated, important questions are being addressed about what produces learning, about what the products of learning are, and about how organisms can represent their world. Moreover, by working in a relatively constrained domain, we can often better characterize what would be adequate answers to questions about the nature of learning and better develop techniques for providing those answers. So one role for Pavlovian conditioning is as a model for the study of modification by experience generally.

A second role for Pavlovian conditioning is to continue to provide a body of data and developed theory that inform adjacent areas of scientific inquiry. The study of Pavlovian conditioning provides information about a learning process of continuing interest to allied fields. Two of the most intensely pursued current areas of interest provide examples: cognitive science and neuroscience. After a period in which it neglected learning processes, modern cognitive psychology has returned to their study; indeed, even the association has regained some respectability. This is especially obvious in the approach to cognitive processes currently called "parallel distributed processing" or "connectionism." According to this approach (e.g., McClelland & Rumelhart, 1986; Rumelhart & McClelland, 1986), many phenomena can be understood in terms of multiple parallel connections between stimulus input and response output. Although fueled by analogies to neural structures and modern computer design, these connectionistic theories clearly harken back to classical associationism. They appeal to multiple associations interacting to produce complex outputs. In some cases, theories of this sort have attacked apparently complex behaviors with surprisingly promising results. For instance, something of speech perception and production, of category learning, and of place recognition can be captured by such theories. It is still too early to know whether these initial results forecast ultimately successful accounts. But they do belie some widely accepted assertions that certain classes of psychological phenomena are in principle beyond the reach of inherently associationistic theories.

Connectionistic theories of this sort bear an obvious resemblance to theories of Pavlovian conditioning. Both view the organism as using multiple associations to build an overall representation, and both view the organism as adjusting its representation to bring it into line with the world, striving to reduce any discrepancies. Indeed, it is striking that often such complex models are built on elements that are tied quite closely to Pavlovian associations. For instance, one of the learning principles most frequently adopted within these models, the so-called delta rule, is virtually identical to one popular theory in Pavlovian conditioning, the Rescorla–Wagner model. Both are error-correction rules, in which the animal uses evidence from all available stimuli and adjusts the strength of each stimulus based on the total error. Here, then, is a striking point of contact between Pavlovian conditioning and a portion of cognitive science.

The second area of intense activity is neuroscience. Although that area has mushroomed and contains many parts that do not border on psychology, one important subarea is the study of the neural bases of learning processes. Neuroscientists have decided, quite rightly I believe, that Pavlovian conditioning provides one of the best-worked-out learning situations for them to analyze. It has a well-developed data base that can be characterized quite successfully by available theories. The hopeful sign is that, increasingly, neuroscientists are familiarizing themselves with the contemporary state of Pavlovian conditioning and are attempting to account for a host of new results, such as sensitivity to information, inhibitory learning, and so forth. Indeed, many neuroscientists are better acquainted with the modern state of Pavlovian conditioning than are psychologists at large. It is partly through that acquaintance that genuine progress is being made in the biological analysis of learning.

Pavlovian conditioning stands between these two very active areas of research. It provides a context in which to assess some of the assumptions about the elements contributing to more complex cognitive theories. It also provides an organized data base and theoretical structure to help inform and guide the neural analysis of learning. The association is not dead, but rather continues to be a fundamental concept in the analysis of learning processes. Moreover, it is in Pavlovian conditioning that many of the important discoveries are currently being made about associative processes. As a result, allied areas will continue to turn to conditioning for data and theory.

Finally, Pavlovian conditioning continues to play the role of generating practical applications. Of course, an early example was the development of some aspects of behavior therapy. Behavior therapy was spun off early and has now developed its own mature literature. In my view, an unfortunate consequence of that early emergence is that some behavior therapists still view conditioning in the way characterized by the quotations that I have criticized. But there continue to be other instances of applications and potential applications stemming from the laboratory study of Pavlovian conditioning. For instance, recent work suggests that the body's reactions to drugs and some diseases involve Pavlovian conditioning mechanisms. Phenomena such as drug tolerance (e.g., Siegel, 1983), stress-induced analgesia, and immunosuppression (e.g., Ader & Cohen, 1981) seem to involve Pavlovian conditioning. Those observations suggest new instances in which conditioning will have relatively direct practical consequences.

Trends come and go in psychology. Topics that are hot today will be cold in 10 or even 5 years, but some parts of psychology continue to build systematic and important data bases and theories. The study of sensory mechanisms is one example. I think that the study of the associative mechanisms underlying Pavlovian conditioning is another. These fields are enduring and systematic, but I hope it is now obvious that they are also changing and exciting.

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